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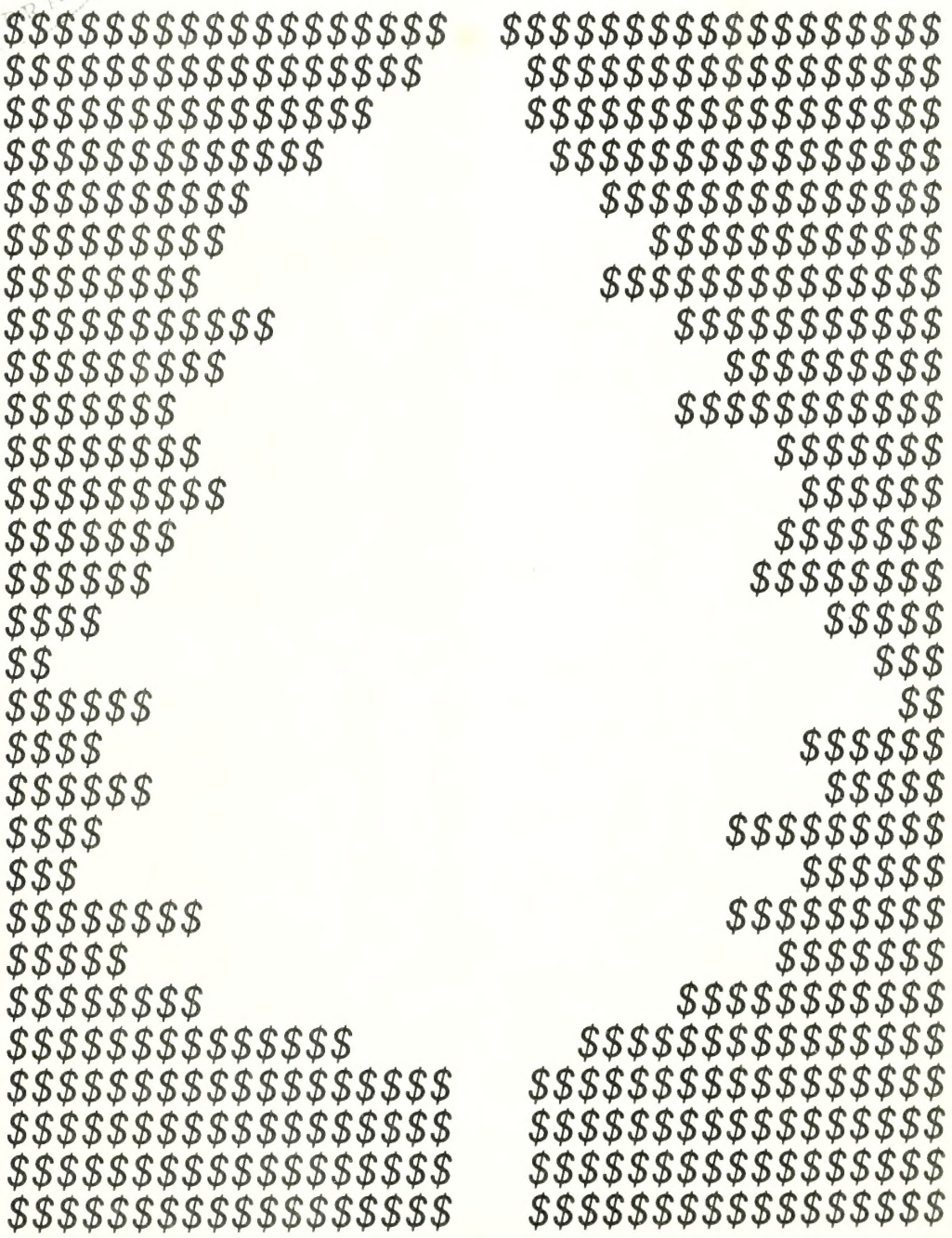
A New Look at Red Pine Financial Returns in the Lake States

David C. Lothner and Dennis P. Bradley



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A NEW LOOK AT RED PINE FINANCIAL RETURNS IN THE LAKE STATES

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Red pine plantations or natural stands make up only 2-½ percent of the Lake States' commercial forests and contain less than 1 billion cubic feet of volume. But wood users as well as land managers like its versatility. Red pine's relatively high strength makes it desirable for girders, joists, studs, and trusses. And because the trees are generally straight with little taper and are easily treated with preservatives, they make ideal poles, posts, pilings, and cabin logs. In addition, red pine is used with other softwoods to manufacture pulp (Kallio and Benzie 1977). As a result, red pine commands higher prices than any other Lake States' softwood species.

New evidence in support of this popular species comes from recent analyses of growth and yield data from established plantations. That study indicates that red pine yields are much greater than previously estimated (Lundgren 1981).

Although the new biological evidence about red pine yields is promising, what about the financial evidence? Which existing and potential red pine sites warrant investment and how should they be managed to achieve the best financial performance?

Using the new biological growth information and recent management and harvest cost estimates, in this note we suggest answers to these questions using two investment criteria: The soil expectation value (SEV) and the internal rate of return (IRR)—both before taxes.[1] For both criteria we calculate a "return to landowner" that assumes that the landowner pays for the harvest as for any other service. This permitted us to ignore stumpage prices, but required us to explicitly examine the impact of all costs to grow, harvest, and transport red pine on our two criteria.

[1]*Definitions of the soil expectation value and internal rate of return are found in most standard forest economics text such as Gregory (1972). A rationale for the use of each criteria is found in Bradley and Lothner (1983).*

ASSUMPTIONS

Although many different market scenarios are possible, this note assumes that both red pine saw logs and chips can be sold. For stands whose average diameter equals or exceeds 9 inches, we assume that saw logs are separated before chipping the remaining tops and smaller stems. Stands averaging less than 9 inches are chipped entirely using slightly smaller, less expensive equipment. We assume high utilization—much higher than currently practiced. However, there is strong evidence to expect higher utilization in the future when plantations established now will be cut.

The management strategies we analyzed and report on are similar to those used by Lundgren (1981). Analyses were made for three site indices—60, 70, and 80 for several combinations of three factors: (1) survival densities of 400, 600, and 800 trees per acre—the number of trees surviving 5 years after planting, (2) residual basal area after thinning of 60, 80, 100, and 120 square feet per acre, and (3) rotation ages of from 50 to 95 years.

We assume the plantations are established by planting 2-year-old seedlings in a square spacing. Subsequent management includes chemical release at 3 and 6 years. Release is followed by thinnings at intervals of not less than 10 years; the first thinning is no earlier than 20 years after planting and only if (1) the height to a 3-inch top diameter inside bark is at least 17 feet, (2) average stand diameter is at least 5 inches, and (3) the thinning removes at least 25 percent of the total basal area.

Establishment and management cost estimates were gathered from industrial and public land managers, researchers, and some published material. As expected, cost estimates vary, resulting in questionable analyses when single cost values are used. However, this problem can be partially solved by performing sensitivity analyses to show the effect of different cost assumptions on SEV.

Bare land for growing red pine in the Lake States is assumed to cost $75 per acre and will be sold for the same price at the end of one rotation. Light mechanical site preparation is assumed to cost $75 per acre, and could include brush raking, disking, and barreling. Planting costs are 11¢ per tree; 5¢ for stock plus 6¢ for the labor to plant it. But because we assume that only three-fourths of the seedlings survive, the established cost per tree is 14.5¢. Chemical release in years 3 and 6 is assumed to cost $30 per acre for each application. A general administration cost of $1.10 per acre as well as the property tax of 60¢ per acre will be charged each year.

Our harvest and transport cost estimates are based on system productivity data assembled from the literature as well as from recent research dealing with full tree chipping and saw log sorting (Bradley, *et al.* 1980, Hypes 1979, and Sibal 1981). Although harvest costs per hour for the two systems are assumed fixed, average stand diameter, basal area, and the proportion of sawtimber effect harvest costs per cunit. Stand diameter, however, is the most important factor. For example, when only chips are produced from a stand with 90 square feet of basal area and an average stand diameter of 9 inches, harvest cost is $15.30 per cunit. Yet, harvest cost declines to $5.70 per cunit (a 64 percent reduction) if the average diameter increases to 18 inches while basal area remains 90 square feet per acre.

Transport cost is also extremely important, amounting to 25 to 50 percent of delivered costs. We assume that each stand lies 25 miles from the mill and transport costs $6.30 per cunit. Sale preparation and sale administration are assumed to cost $81 per acre for each thinning and $106 per acre for a clearcut.

Prices for sawtimber and pulpwood were gathered from Lothner *et al.* (1982). We assume that chips will return $55 per cunit and sawtimber will return $90 per cunit FOB mill.

RESULTS

Assuming a 4-percent discount rate, SEV increases three times ($268 to $842 per acre) when site index increases from 60 to 80. Yet optimum initial stocking is constant for all sites examined (400 surviving trees per acre). However, optimum basal area after thinning does increase from 80 square feet per acre for site index 60 to 100 square feet for site index 70 and 80 (table 1). Higher site indices also lower optimum rotation age slightly, but varying the age of final harvest even 10 years, plus or minus, has little effect on financial outcome.

The discount rate chosen strongly affects SEV. For the site index 60 analyses, all SEV's are positive with a 4-percent discount rate but negative with a 6-percent discount rate. Optimum rotation age also occurs earlier with higher discount rates.

Results are similar regarding IRR, which increases a whole percentage point as site index increases from 60 to 70 and from 70 to 80. Similarly, optimum initial stocking and optimum basal area after thinning do not change with site. Finally, optimum rotation age also shows little change as site increases, when IRR is the criterion (table 2).

Just how sensitive are either SEV or IRR to changes in initial stocking level and residual basal area? For site index 60, if one increases initial stocking from 400 to 600 trees per acre, SEV can decline as much as 28 percent and IRR can decline as much as 10 percent (table 3).

Our sensitivity analysis to identify how each cost or revenue factor affects financial performance indicated that the most important factors are product price followed by harvest and transport cost. Relatively small changes in either of these two factors have a large impact on the financial performance of any management strategy.

Table 1.—*Red pine management strategies achieving a maximum soil expectation value at a 4 percent discount rate on three sites for a saw log and chip market*

Site index	SEV	Rotation age	Initial stand density	Residual basal area	Total output	Mean annual increment
	$/acre	*Years*	*Trees/acre*	*Ft^2/acre*	*Cunits*	*Ft^3/acre/y*
60	268	65	400	80	71	110
70	520	65	400	100	101	156
80	842	60	400	100	114	190

Table 2.—*Red pine management strategies achieving a maximum internal rate of return on site indices 60, 70, and 80 for a saw log and chip market*

Site index	IRR	Rotation age	Initial stand density	Residual basal area	Total output	Mean annual increment
	Percent	*Years*	*Trees/acre*	*Ft²/acre*	*Cunits*	*Ft³/acre/y*
60	5.0	55-65	400	80	59	107
70	6.0	60	400	80	83	138
80	7.0	55	400	80	93	169

DISCUSSION

With current Lake State prices for saw logs and pulpwood, growers can apparently earn real returns of 5, 6, and 7 percent on red pine sites 60, 70, and 80, respectively. Again, by real rates, we mean that if inflation occurs, all prices and costs will undergo the same relative changes. Soil expectation values for these three sites are $268, $520, and $842 per acre.

We must emphasize that these results are only indicative. Although much of the data are very good, especially the red pine growth data, no one really knows what future prices will be, yet prices have the most important effect on the outcome. Although the harvest and transport cost data are speculative, they reflect the realistic range of costs expected.

An important point to consider is that the optimum levels of initial stocking, basal area after thinning, and rotation age suggested in our analysis, differ dramatically from practices recommended in the past. This difference occurs primarily for two reasons. First, we assume no real red pine price increases over the rotation. Most previous financial analysis of red pine have assumed that prices will increase from 1 to 3 percent per year relative to costs. The effect of these more optimistic price and cost assumptions is the same as assuming much more rapid growth rates. And, of course, if one can expect volumes to be worth more, the longer one waits, rotation ages will necessarily be higher than those suggested here. Second, our harvest cost assumptions reflect a very strong inverse exponential relation between tree diameter and cost. Our recommended initial stocking level of 400 trees per acre, while producing slightly less total volume over the rotation than 800-1,000 trees per acre, results in much larger trees than previously recommended initial levels. Tree diameters are about twice as large at the lower initial stocking recommended here (Lundgren 1981) and cost very much less to harvest per unit volume.

Thus, many factors affect the future financial success of red pine investments. And it is important that managers keep abreast of them all.

Table 3.—*SEV and IRR for red pine, site index 60, saw log and chip market*

Initial stand density	Basal area after thinning (ft²/acre)			
	60	80	100	120
		SEV at 4%		
		Dollars per acre		
400	222	268	263	249
600	229	235	236	192
		IRR		
		Percent		
400	4.9	5.0	4.9	4.8
600	4.8	4.8	4.8	4.5

[1]Definitions of the soil expectation value and internal rate of return are found in most standard forest economics text such as Gregory (1972). A rationale for the use of each criteria is found in Bradley and Lothner (1983).

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Lothner, David C.; Bradley, Dennis P.
A new look at red pine financial returns in the Lake States. Res. Pap. NC-246. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 4 p.

Describes the financial performance of red pine on site index 60, 70, and 80 lands by using new yield evidence and up-to-date cost and revenue assumptions. Best combinations of initial stocking, residual basal area after thinning, and rotation age are identified for two different financial criteria: soil expectation value and internal rate of return.

KEY WORDS: Soil expectation value, internal rate of return, *Pinus resinosa*, economics, timber management.

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Biomass in Conifer Plantations of Northeastern Minnesota

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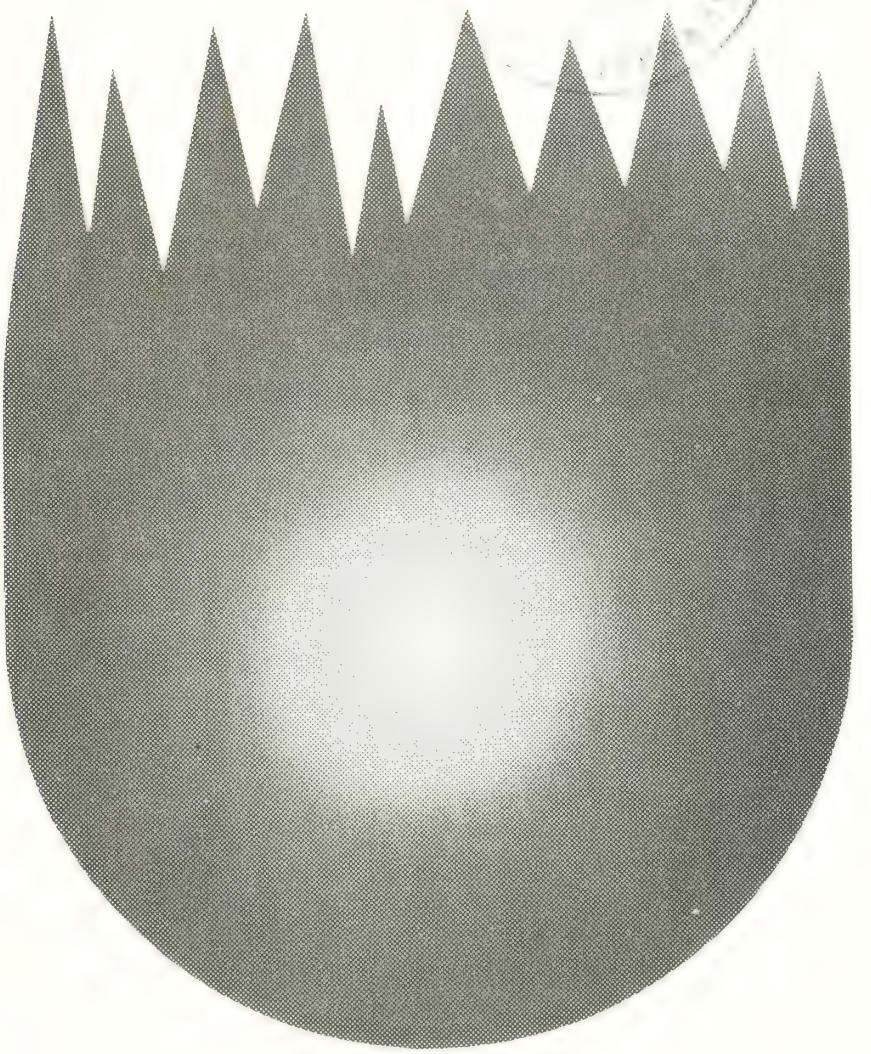

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BIOMASS IN CONIFER PLANTATIONS OF NORTHEASTERN MINNESOTA

Lewis F. Ohmann, *Principal Plant Ecologist*

Establishing conifer plantations in the Great Lakes Region generally requires site preparation prior to planting and release from competing vegetation several years after planting.A good deal is known about the response of the planted trees to these silvicultural practices, but little has been reported on the response of the rest of the vegetative community in plantations. The other vegetative components of a plantation not only influence the planted trees but also the other resources, especially wildlife habitat, that managers are required to provide.

The response of tall shrub undergrowth to silvicultural practices in 53 conifer plantations from northeastern Minnesota was recently described (Ohmann 1982). This report quantifies the overall response in terms of biomass of the various plant strata and particularly the low shrub-herb layer in the same plantations. It also compares plantation biomass with other reported planted and natural community biomass values.

Biomass is a useful measure for understanding plant community dynamics (Whittaker 1962, Whittaker and Woodwell 1968). Biomass integrates plant species size (dominance) and numbers and also permits comparison of morphologically different species (Balogh 1983).

More than 300,000 acres of conifer plantations have been established in the Superior National Forest. Conifer plantations made up about 10 percent of the Forest's Isabella and Halfway (now part of the Kawishiwi) Ranger Districts at the time this study was conducted (1976-77) (Peek *et al.* 1976).

The acreage of conifer plantations in northeastern Minnesota will probably increase in response to more intensive forest management mandated by legislation that restricts timber harvest in the nearby Boundary Waters Canoe Area Wilderness.

METHODS

Field

Study plantations on relatively uniform soils (coarse loamy Dystric Eutrochrepts)[1] were selected from within a 33-mi^2 area near Isabella, Minnesota (lat. 47° 35′N, long. 91° 20′W). Parts of the area had been logged for red pine (*Pinus resinosa* Ait.) and white pine (*Pinus strobus* L.) during northern Minnesota's early logging period (ca. 1900-1920). However, the sample was selected from plantations established following the clearcut of natural stands of pine (jack pine, *Pinus banksiana* Lamb.) or mixed pine and spruce (usually black spruce, *Picea mariana* (Mill.) B.S.P.) during the mid-1940's through the 1970's.

Samples were selected to represent a spectrum of plantation ages and of silvicultural techniques practiced in the study area during the 30-year period. Plantation establishment dates, tree species planted, and site preparation and plantation release methods were depicted with overlays on a cover-type map of the area (Hagen and Meyer 1977). Based on the overlays plantations were arbitrarily classed by 5-year age classes from earliest available (1945-1949) to most recent (1970-1974) at the time of the study.The plantations were categorized on the basis of tree species planted and on the basis of two silvicultural practices: (1) site preparation for planting, and (2) release from competing vegetation.

Site preparation methods included: (1) no known site preparation treatment; (2) mechanical disking of the ground surface, probably by an Athens-type disk plow (Rudolf 1950); (3) dozer-blade shearing of woody stems and scraping at least some of the forest floor material and depositing it in specific areas, generally

[1] *Personal communication with D. F. Grigal.*

windrows (rock-raking[2]) (Noble *et al.* 1977); and (4) applying chemical herbicide (usually either 2,4-D or a mixture of 2,4-D and 2,4,5-T) to the post-logging vegetation. Plantation release methods included: (1) foliar application of chemicals (in more recent years usually 2,4-D herbicide applied by helicopter (Hagen and Meyer 1977), but earlier could have included a mixture of 2,4-D and 2,4,5-T applied from fixed-wing aircraft); (2) manual (hand removal of competing vegetation at least once); (3) manual plus chemical (a combination of both types of release, usually a manual release followed by a chemical release several years later); and (4) unknown (no record of release). Tree species planted were categorized as: (1) pine (red pine, jack pine, or a combination of both); (2) pine and spruce (white spruce, *Picea glauca* (Moench) Voss); or (3) spruce.

The plantations were chosen on the cover-type map and overlays by using random numbers selected from right angle baselines drawn on the map. Samples were drawn until at least three sites were picked to represent all combinations of categories of species planted, site preparation, and plantation release practiced within each of the 5-year establishment periods. Because silvicultural technology changed, not all of the listed practices were represented in each establishment period. For example, sites were not prepared by disking in plantations established after 1964, chemical site preparation was not practiced before 1965, all plantations established after 1965 had some type of site preparation, and rock-raking was not used until 1960.

Trees greater than 1 inch diameter at breast height were sampled by the point-centered quarter method (Cottam and Curtis 1956). This method would not normally be used to sample regularly spaced trees such as in plantations. However, most of the trees were not evenly spaced because a significant number of nonplanted trees were present (about 20 percent of the sample) and not all planted trees survived. We modified the quarter method such that biomass was determined for each point and then averaged over all points. Used in this way, the method is similar to a plotless basal area estimation. The use of a 1 inch diameter at breast height limit meant that in young plantations it was possible that some (and occasionally all) of the trees sampled were nonplanted individuals that had not been removed during harvest, had not been killed during site preparation, or had sprouted following site preparation and reached diameter growth beyond the lower sampling limit.

[2] *A more accurate term currently used for this general form of treatment is "tractor scarification".*

The first sample point was randonly selected and the remaining points were spaced about 60 feet apart in a block design of 4 rows of 5 points or 5 rows of 4 points. The direction of travel from point to point constituted one line and an imaginary line was drawn perpendicular to it, forming 4 quadrants around each point. At each point we recorded the distance to the closest tree in each quadrant (to the nearest foot) and the species and d.b.h. (to the nearest one-tenth inch).

Low shrubs, fern and fern allies, herbs, mosses and lichens were recorded as the percent of ocular ground cover they projected within a 1 by 2 foot plot at each of the 20 tree sampling points (Ohmann and Ream 1971a). Sampling was conducted throughout the growing season. Some species were difficult to identify during certain times so some species were grouped; for example, all grass species were treated as a single unit.

Analyses

Tree diameters were used in appropriate equations developed for each species from this or similar regions to estimate the aboveground ovendry biomass represented by each tree (Barney *et al.* 1978, Crow 1983, Green and Grigal 1978, Harding 1982, Ker 1980, Kinerson and Bartholomew 1977, Koerper and Richardson 1980, Monteith 1979, Pastor and Bockheim 1981, Pollard 1972, Schmitt and Grigal 1981, and Young *et al.* 1980).

For the traditional point-centered quarter method, tree diameter and distance data are collected at a number of points (usually 20 or more) in a stand. The data are then aggregated by summation over all points, and tree density and basal area are calculated on the basis of aggregated data. In this study, however, we performed the appropriate computations for biomass on data collected at each point. Summary statistics were then developed for relevant data from each point, generating means and variances. The advantage of this approach is the ability to develop measures of variation for the data.

The low shrub, herb, and fern and fern ally cover data from each plot were used in biomass estimation equations developed for species or species groups for this area (Ohmann *et al.* 1981). Average cover of mosses and lichens were converted to biomass estimates using equations based on additional sampling within northeastern Minnesota.

Total plantation herb layer biomass and biomass of major species or species groups were subjected to

logarithmic transformation and analyzed for difference within treatments by one-way analyses of variance (ANOVAs) and among treatments by three-way ANOVAs.

The effect of treatment categories was also assessed through Multiple Classification Analysis (MCA) (Andrews *et al.* 1973). MCA is a multivariate technique for examining the simultaneous interrelations between several treatments and a dependent variable. It is especially useful if the treatments are correlated to some degree and the attributes examined are not experimentally manipulated (Nie *et al.* 1975), as in this study. A unique feature of MCA is the ability to show the effect of each treatment category on the dependent variable (biomass) both before and after accounting for the effects of the other treatment(s) being considered. For MCA, a grand mean for the dependent variable (biomass) and for category means of each treatment are computed and are expressed as deviations from the grand mean after adjusting for other treatments. These adjusted values indicate the "true" effects of the treatment category on the dependent variable—the effects remaining after accounting for the variation due to other treatments.

RESULTS AND DISCUSSION

The sample consisted of nine or more plantations for each of the establishment periods except for 1970-1974 when not enough plantations were available for sampling (table 1). Some of the PREP, RELEASE, and SPECIES categories also had limited representation so only three samples were selected from each of them because of their scarcity in the plantation population (table 1).

Two of the independent variables, YEAR and PREP, were significantly positively correlated. This probably reflects changes in site preparation practices. YEAR and SPECIES, as well as PREP and SPECIES, were slightly positively related. YEAR and RELEASE, PREP and RELEASE, and SPECIES and RELEASE were weakly negatively related:

Independent Variable	Pearson's R	Probability
YEAR-PREP	0.7134	0.000
YEAR-RELEASE	-0.1100	.216
YEAR-SPECIES	.2022	.073
PREP-RELEASE	-0.0691	.312
PREP-SPECIES	.1378	.162
RELEASE-SPECIES	-0.1569	.131

It is important to recognize the degree of correlation because positively related treatments, when considered together, will explain less of the variation than when considered separately and added together. On the other hand, negatively related treatments that are positively related to the dependent variable will, when considered together, explain more of the variation in the dependent variable than when considered separately and added together. The independent variables YEAR and PREP are correlated sufficiently so that when considered together in an ANOVA or MCA the amount of variation explained is less than actually present.

Ecological landtypes (ELTs) for the Superior National Forest recently have been described, although they have not been mapped extensively. The most probable ELTs for the plantations in this study are: ELT-11 (UDHD) Upland Deep Loamy over Sandy Dry, ELT-13 (UDLDC) Upland Deep Loamy Dry Coarse, and ELT-14 (UDLDM) Upland Deep Loamy Dry Medium. These ELTs are estimated to occupy 10, 8, and 11 percent of the land area within the Superior National Forest, respectively. The results presented here would be most applicable to conifer plantations located on these ELTs.

Plantation and Strata Biomass

Generally, biomass increases with plantation age. In this case total plantation biomass[3] ranged from

[3] *Total biomass does not include conifer tree seedlings under 1 inch d.b.h..*

Table 1.—*Independent variable categories used to analyze the biomass estimates of the plant strata in 53 conifer plantations near Isabella, Minnesota*

Establishment period		Site preparation		Plantation release		Species planted	
YEAR	Plantations	PREP	Plantations	RELEASE	Plantations	SPECIES	Plantations
	Number		*Number*		*Number*		*Number*
1945-1949	9	None	11	Chemical	17	Pine	38
1950-1954	9	Disk	21	Manual	21	Pine and spruce	12
1955-1959	9	Rock-rake	18	Manual plus chemical	3	Spruce	3
1960-1964	13	Chemical	3	No record	12		
1965-1969	9						
1970-1974	4						

135,100 lbs/acre[4] in the oldest (26- to 30-year-old) to 40,500 lbs/acre in the 11- to 15-year-old plantations but then increased to 66,500 lbs/acre in the youngest plantations (table 2). Excluding the tree component, the mean biomass of all other strata was 3,100 lbs/acre. The nontree biomass from the oldest to the youngest plantation was distributed about as expected and the differences are minor between them. The greatest deviation from the mean in the nontree group was a plus 760 lbs/acre in the 21- to 25-year-old plantations and the next greatest was a minus 510 lbs/acre in the 1- to 5-year-old plantations. Therefore, the anomaly in biomass distribution by plantation age is primarily attributable to the the tree stratum. In the younger plantations fewer planted trees were large enough to be included in the sample limit of 1 inch d.b.h. and thus proportionally more nonplanted trees—trees not taken in the earlier harvest operation and not killed in site preparation, or trees that sprouted following site preparation and grew beyond the diameter limit—were included in the sample. These trees, sometimes large hardwoods, contributed a greater biomass for the tree stratum than expected in the younger plantations.

Although the literature contains few reports of biomass for young conifer plantations (Cannell 1982), total community biomass has been reported for both natural broadleaf and conifer stands and for some plantations in the region. A 32-year-old red pine plantation in Wisconsin representing 163,200 lbs/acre was reported by Wilde (1967). Biomass in 50+ year-old natural jack pine communities in northern Minnesota ranged from 73,500 lbs/acre on granite to 134,800 lbs/acre on deep till (Green and Grigal 1979). The older Isabella plantations fall within the range of most of the conifer communities listed above.

The biomass of the oldest Isabella plantations (135,000 lbs/acre) also compared favorably with reported nonpine community biomass values. Reiners (1972) reported biomass of a mature upland oak forest as 111,100 lbs/acre, a marginal fen forest as 88,100 lbs/acre, and a cedar swamp forest as 142,400 lbs/acre. Ovington (1963) found 146,700 lbs/acre of biomass in an upland oak woodland in Minnesota. From 37- to 39-year-old aspen near Dorset, Ontario, had 53,100 lbs/acre and 41-year-old aspen near Lake Itasca, Minnesota, 185,200 lbs/acre of biomass, respectively (Bray and Dudkiewicz 1963). A northern Minnesota 5-year-old aspen sucker stand contained 33,800 lbs/acre of biomass, and a mature aspen stand 132,800 lbs/acre (Silkworth and Grigal 1982). A poorly drained alder (*Alnus rugosa* (Du Roi) Spreng.)-ash (*Fraxinus nigra* Marsh.) swamp in northern Michigan had a biomass value of 47,300 lbs/acre and a well-drained alder-ash swamp (mostly alder) 27,700 lbs/acre (Parker and Schneider 1975).

Other studies report only the biomass of the tree component. Mean tree biomass in a series of 24- and 25-year-old jack pine plantations at three Lake States locations ranged from 64,400 to 102,100 lbs/acre (Zavitkovski *et al.* 1981). The lower biomass plantations were located near Isabella, Minnesota and this study site. The value for this site was the mean of 50,398, 64,670, 69,398, and 73,055 lbs/acre of jack pine biomass. In Vermont 10-year-old jack pine plantations contained 11,900, 15,300, 24,400, and 30,500 lbs/acre of tree biomass when planting space was varied (Adams 1928). And 40-year-old jack pine in central Minnesota contained 132,284 lbs/acre of jack pine biomass (Alban *et al.* 1978). Tappeiner and John (1973) reported that biomass in 50- to 90-year-old jack pine stands in Southern Minnesota ranged from 86,700 to 112,900 lbs/acre. Red pine plantations of 29, 30, and 31 years of age contained 41,210, 49,506, and 48,971

[4] *To convert from lbs/acre to kg/ha, divide by 0.8922.*

Table 2.—*Above-ground ovendry biomass by stratum for 53 conifer plantations near Isabella, Minnesota*

Stratum	Plantation age					
	1-5	6-10	11-15	16-20	21-25	26-30
	Pounds/acre					
Tree (>1 inch d.b.h.)	63,885	50,221	37,627	62,811	73,382	131,902
Tall shrub (plus hardwood trees < 1 inch d.b.h.)	2,034	2,332	2,035	2,086	2,914	2,631
Low shrub[1]	25	101	185	109	166	137
Herb	276	266	312	317	437	176
Fern and fern ally	77	60	132	96	156	82
Moss	107	268	250	156	165	156
Lichen	71	89	45	116	18	18
Total	66,475	53,337	40,586	65,691	77,238	135,102

[1]Raspberry (*Rubus strigosus*) and rose (*Rosa acicularis*) were included in the tall shrub stratum.

lbs/acre, respectively (Madgwick *et al.* 1970). Mature central Pennsylvania red pine plantations at tree densities of 435, 907, and 1,210 trees/acre had 172,156; 207,925; and 166,536 lbs/acre of biomass, respectively (Singer and Hutnik 1966). The pine biomass of the older Isabella plantations was within the range of all but the mature red pine plantations reported above (fig. 1).

No Lake States reports of biomass for nontree vegetation strata in young conifer plantations were found to directly compare with the biomass values of the Isabella plantations. Biomass has been reported for other types of plant communities by various strata; however, the definition of what is included in each stratum differs greatly. Mature jack pine communities on various bedrock types and soil depths in northern Minnesota (Green and Grigal 1979) contained more moss and lichen biomass (616 to 4,202 lbs/acre) than the 174 to 357 lbs/acre in the Isabella plantations (table 2). Biomass of the low shrub, herb, and fern and fern ally components of the mature jack pine communities were more similar to the plantations ranging from 187 to 509 lbs/acre and from 378 to 759 lbs/acre on the Isabella sites (table 2). The tall shrub stratum among plantations was much more uniform than among the mature stands where it ranged from 71 lbs/acre on Gabbro bedrock with shallow soils to 2,600 lbs/acre on deep till soils (Green and Grigal 1979). The difference in total undergrowth biomass in the mature stands (mean of 4,305 lbs/acre) and the plantations (mean of 3,100 lbs/acre) was due primarily to more moss and lichen biomass and less tall shrub biomass in the mature stands. The shrub component of a 40-year-old jack pine stand in north-central Minnesota contained 2,587 lbs/acre of biomass (Alban *et al.* 1978). Undergrowth biomass of 5-year-old postfire communities resulting from natural seeding to jack pine or sucker regeneration of aspen ranged from 1,468 lbs/acre in an aspen-birch-jack pine type to 5,099 lbs/acre in a ridgetop jack pine-oak community (Ohmann and Grigal 1979). Three of the 7 communities exceeded the amount of undergrowth biomass occurring in the 1- to 5-year-old plantations. The difference was due mainly to greater amounts of low shrubs in the postfire communities. The plantations exhibited a general increase in total undergrowth biomass with age (table 2). Based on the northern Minnesota mature jack pine communities, plantation undergrowth at 30 years had not yet peaked.

Biomass by strata has been reported for several broadleaf communities in the region. Shrub biomass of mature aspen, aspen-maple-birch, and maple-birch-aspen communities in Wisconsin was 1,540, 720, and

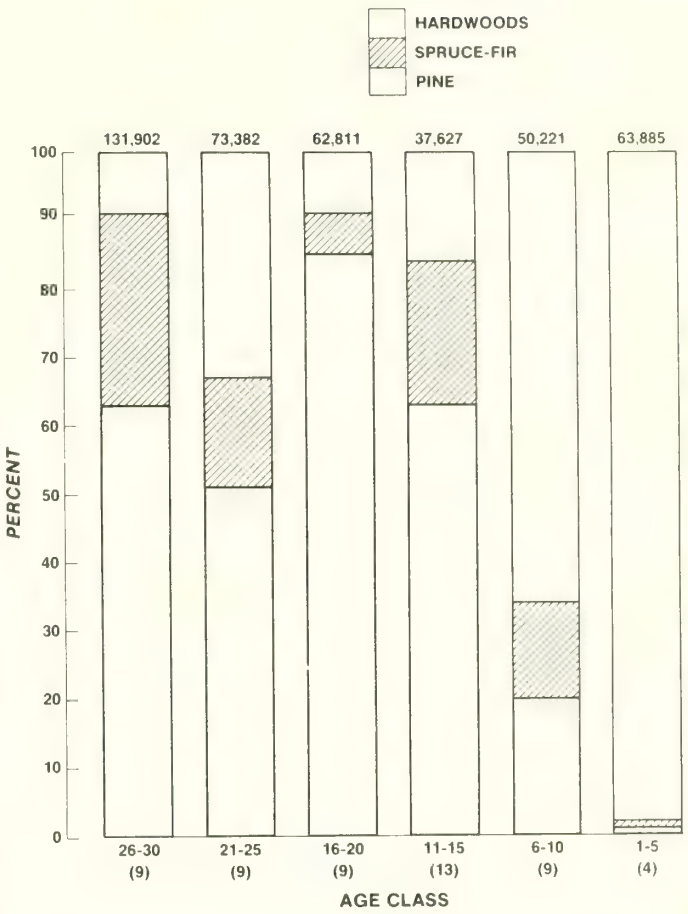

Figure 1.—*Percent pine, spruce-fir, and hardwood tree (>1 inch d.b.h.) above-ground ovendry biomass (pounds/acre) by age class (YEAR) of 53 conifer plantations near Isabella, Minnesota. Average total tree biomass at top of bar. Numbers in parentheses indicate number of plantations in each catagory.*

340 lbs/acre, respectively; ground cover was 1,240, 480, and 600 lbs/acre; and total undergrowth was 2,780, 1,200, and 940 lbs/acre (Crow 1978). Mature aspen communities at Dorset, Ontario, and Lake Itasca, Minnesota, contained undergrowth biomass values similar to the Wisconsin stands at 1,490 and 785 lbs/acre (Bray and Dudkiewicz 1963). These values were much less than either the plantations or other communities noted above. A 5-year-old aspen sucker stand and a mature aspen stand in northern Minnesota had tall shrub biomass values of 3,400 and 3,740 lbs/acre, respectively (Silkworth and Grigal 1982), which was higher than the Isabella plantations; but the other undergrowth biomass (900 lbs/acre) was within the range of that in the plantations.

More studies are needed to determine if the biomass represented in vegetative strata of plantations is similar to other plant communities of the region. Based on the available evidence, at least the nontree

component biomass of plantations seems to be near that found in nonplanted communities.

Tree Biomass

Red, white, and jack pine biomass comprised at least 50 percent of the tree stratum in plantations where the planted trees had time to grow large enough to be included under the sample scheme used (fig. 1). In the two younger plantation classes, pine comprised only 20 and 1 percent of the biomass. Spruce and fir species (white spruce, black spruce, balsam fir (*Abies balsamea* (L.) Mill.) and white-cedar (*Thuja occidentalis* L.) comprised from 5 to 28 percent of the tree biomass except in the youngest plantations (fig. 1). Some of the spruce-fir biomass represented planted white spruce; the remainder was due to natural regeneration of the other species and an occasional fir tree that remained from the earlier harvest. The nonplanted hardwood tree biomass (quaking aspen (*Populus tremuloides* Michx.), bigtooth aspen (*P. grandidentata* Michx.), birch (*Betula papyrifera* Marsh.), and red maple (*Acer rubrum* L.) ranged from 98 percent in the 1- to 5-year-old plantations (due in part to the sampling scheme) to 9 percent in the older plantations (fig. 1).

The sequence of declining mean tree biomass from no site preparation through disking, rock-raking, and chemical preparation (fig. 2) may reflect the partial age sequence also present in figure 1. As indicated earlier, independent variables YEAR and PREP were strongly related. However, all four 1- to 5-year-old plantations fell within the third ranked rock-rake category. Thus, in spite of the correlation between age and site preparation, more hardwood biomass seemed to be associated with the rock-rake treatment. Rock-raking can promote sprouting and suckering of hardwood species. Even when the 1- to 5-year-old plantation biomass was removed from the rock-rake rake category, the hardwood percentage was still 55 percent (fig. 2). More spruce-fir biomass was associated with the chemical site preparation treatment, probably because this treatment was used on sites planted to white spruce. The spruce-fir biomass associated with no site preparation was most likely due to natural regeneration of black spruce and some fir retained from earlier logging. The disked sites contained 30 percent more pine biomass than the nontreated sites.

The largest biomass by plantation release treatment was found in the 12 plantations with no record of release (fig. 3), which, along with the manually released plantations tended to be older (mean = 18+ years). The second highest biomass was in the 17

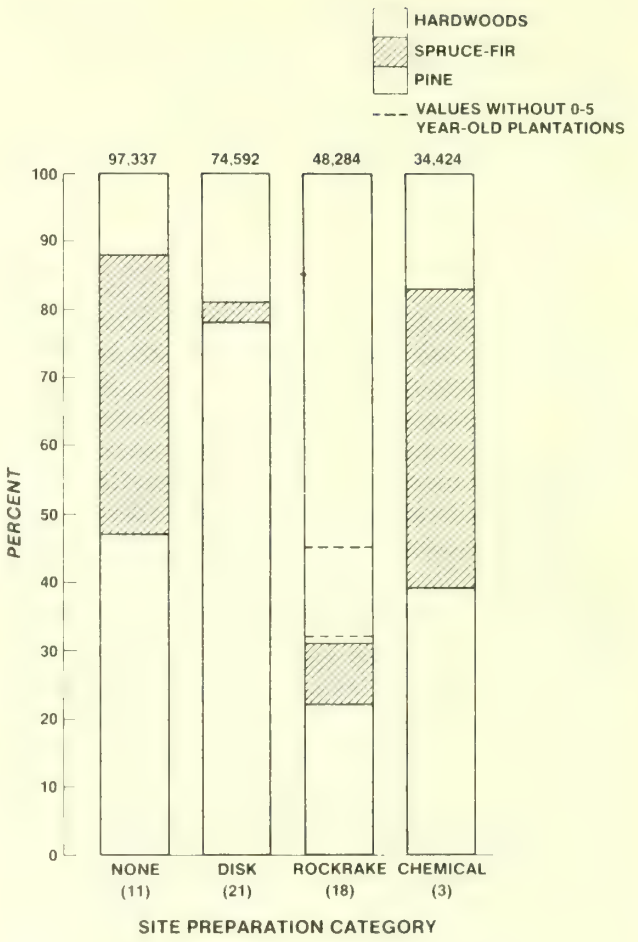

Figure 2.—*Percent pine, spruce-fir, and hardwood tree (>1 inch d.b.h.) above-ground ovendry biomass (pounds/acre) by site preparation treatment category (PREP) for 53 conifer plantations near Isabella, Minnesota. Dotted lines indicate percent values without 0-5-year old plantations. Average total tree biomass at top of bar. Numbers in parentheses indicate number of plantations in each category.*

chemically released plantations that included plantations of of all age classes but had more 11- 15-year-old members (mean = 14+ years). Hardwood tree biomass comprised from 23 to 41 percent of the treatment categories, with most hardwood biomass under conditions of no recorded release and least hardwood biomass under the chemical release treatment (fig. 3). Spruce-fir biomass was greatest in the chemical release category partly because the sites planted to spruce were within that treatment (fig. 3).

Most of the plantations (n=38) were planted to red and/or jack pine (fig. 4). This category included most of the older plantations, thus overall mean biomass (76,800 lbs/acre) was larger for sites planted to pine.

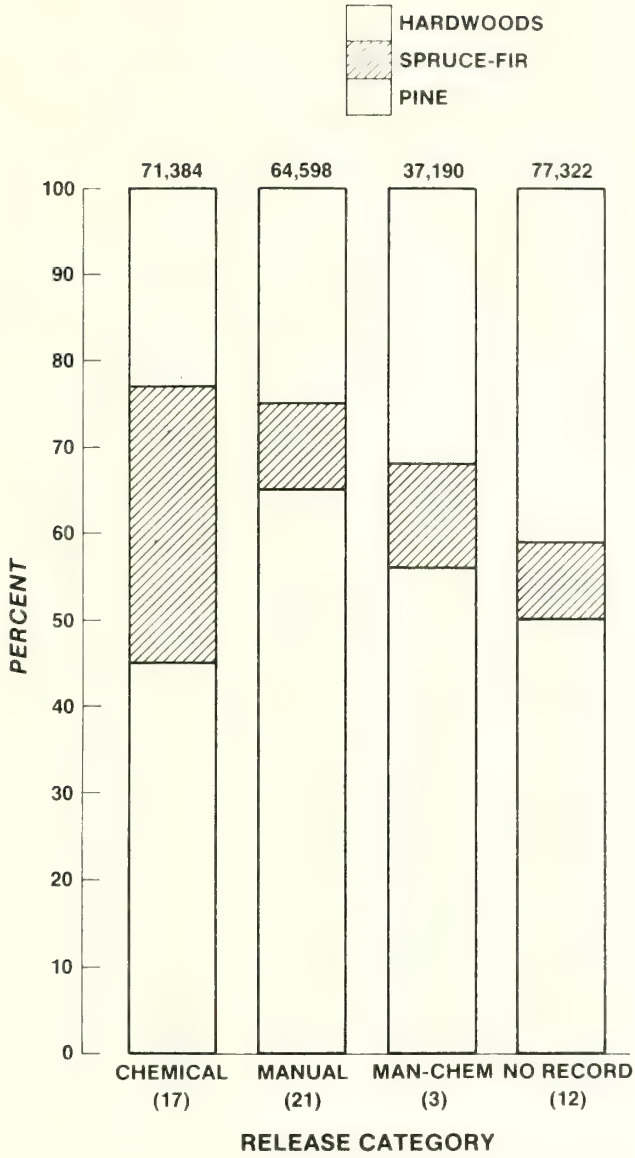

Figure 3.—*Percent pine, spruce-fir, and hardwood tree (>1 inch d.b.h.) above-ground ovendry biomass (pounds/acre) by release category (RELEASE) for 53 conifer plantations near Isabella, Minnesota. Average total tree biomass at top of bar. Numbers in parentheses indicate number of plantations in each category.*

The three 6- to 10-year-old sites planted to spruce had sufficient naturally regenerated jack pine and spruce that the percentage of biomass of the two species groups was about equal (fig. 4); but the mean total biomass was much lower. Hardwood tree biomass was about 20 to 30 percent, regardless of the conifer species planted (fig. 4).

Except for the youngest plantations, plantations were successfully established with about 80 percent pine and/or spruce and 20 percent hardwoods. The site

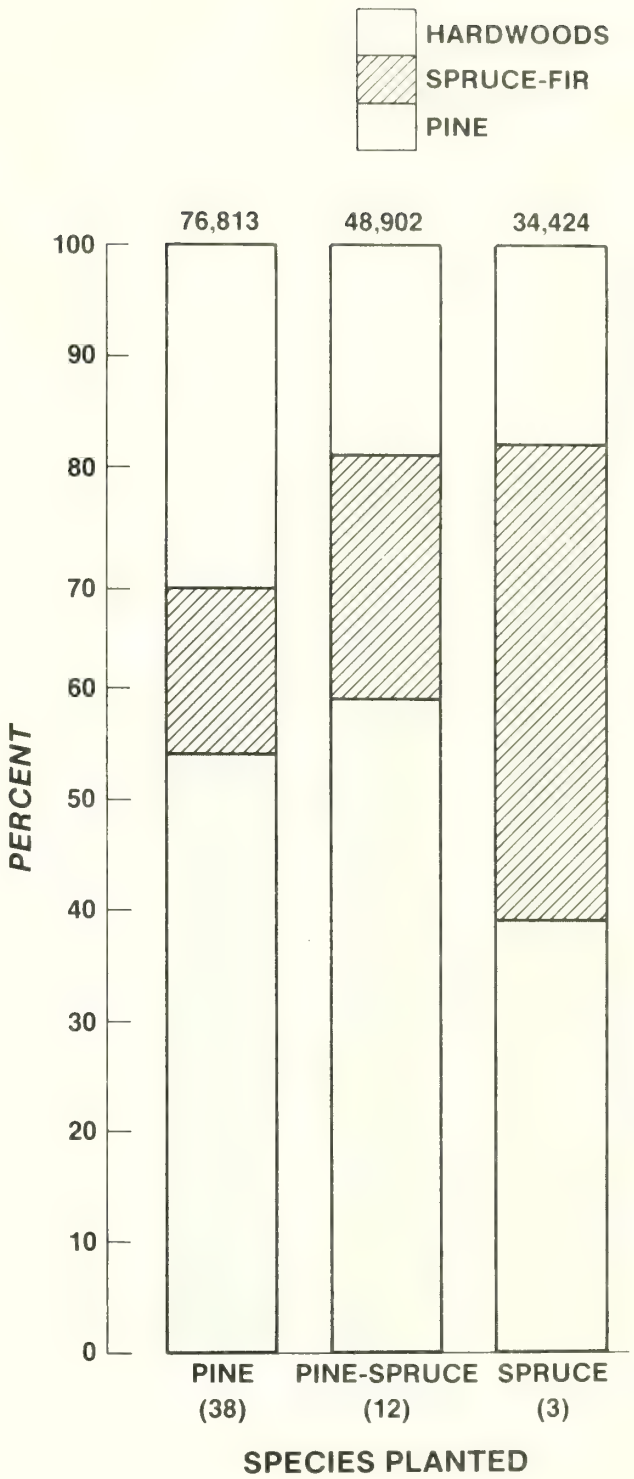

Figure 4.—*Percent pine, spruce-fir, and hardwood tree (>1 inch d.b.h.) above-ground ovendry biomass (pounds/acre) by species planted category (SPECIES) for 53 conifer plantations near Isabella, Minnesota. Average total tree biomass at top of bar. Numbers in parentheses indicate number of plantations in each category.*

preparations, planting, and release treatments were moderately successful, allowing a natural regeneration component of both conifers and hardwoods along with the planted species. Total tree component of the plantations is not only fairly diverse but also within the range of other conifer plantations and natural conifer and hardwood stands of similar age within this region.

Low Shrub and Herbaceous Stratum Biomass

The same herbaceous and low shrub species typical of natural plant communities of the area were also prominent in the plantations (Ahlgren 1960, Grigal and Arneman 1970, Ohmann and Ream 1971b, Ohmann *et al.* 1973). Of herbs, only large-leaf aster (*Aster macrophyllus* L.) and grass occurred in the sample plots of all plantations; and they, along with bracken fern (*Pteridium aquilinum* (L.) Sw.) also had the highest mean estimated biomass (table 3). Bush honeysuckle (*Diervilla Lonicera* Mill.) and late sweet blueberry (*Vaccinium angustifolium* Ait.) were found in 49 of the 53 sample plantations (table 3); and they, along with sweet fern (*Comptonia perigrina* B.& B., Small, Rydb.), wintergreen (*Gaultheria procumbens* L.), bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) and velvet-leaf blueberry (*Vaccinium mytilloides* Michx.), dominated the low shrub biomass (table 3).

In addition to total herb-low shrub layer biomass, 29 species or species groups were represented by sufficient biomass in the various categories to test for differences within treatments by ANOVA. One-way ANOVA of herbaceous and low shrub biomass values within each of the YEAR, PREP, RELEASE, and SPECIES treatments showed few significant differences among categories (Appendix tables 1-4).

Three-way ANOVAs were conducted to examine the combined effects of the silvicultural practices, in addition to individual treatment effects, on the estimated herbaceous and low shrub biomass. Some ANOVAs were not computed because of the close relationship between chemical site preparation and spruce species planted (PREP and SPECIES).

The relation of biomass to each treatment category is difficult to interpret because of the complex relation of treatments and categories and their influence on biomass. The ANOVA and MCA analyses help to clarify these relations by making it possible to examine the influence of a treatment and its categories after adjusting for the effect of the other treatments. Below, I present summary interpretations of these analyses. However, because the interpretations are based on adjusted values, the summary does not always conform to the levels depicted in figure 5.

Wood anemone

Anemone quinquefolia L., a small herb of mesic to moist woods, was sampled in 29 of the plantations and in all treatment categories; but its estimated mean biomass was low—less than 1 lb/acre (table 3). Greater amounts of biomass were associated with younger plantations (except those chemically prepared for planting to spruce); pine plantations; plantations without site preparation; and those prepared by rock-raking. Lesser amounts of biomass were associated with older plantations; sites prepared by disking or use of chemicals; plantations released by manual plus chemical or only chemical treatment; and plantations prepared chemically for planting to spruce. Individual treatment importance in explaining variation in wood anemone biomass ranked PREP (42 percent), YEAR (37 percent), RELEASE (30 percent), and SPECIES (28 percent). The treatment combination YEAR-PREP-RELEASE accounted for 41 percent of the variation in wood anemone biomass.

Spreading dogbane

Apocynum androsaemifolium L., a widespread species common throughout upland forests in northeastern Minnesota, occurred in only 15 of the plantations but was represented in all treatment categories. Its estimated biomass averaged about 4 lbs/acre (table 3). More biomass was associated with younger plantations; manual plus chemical release; and pine-spruce plantations. Less biomass was associated with older pine plantations with no record of release. The individual treatments ranked YEAR, (70 percent), RELEASE (32 percent), and SPECIES (24 percent) in importance; and combined they accounted for 71 percent of the variation in dogbane biomass.

Wild sarsaparilla

Aralia nudicaulis L. is a perennial herb common in moist to dry woods. It was sampled in 44 of the plantations and in all treatment categories with a mean biomass of 7 lbs/acre (table 3). More biomass was associated with older pine plantations that had no site preparation but were later given a manual plus chemical release. Lower biomass values were related to younger plantations; disk preparation sites or sites chemically prepared for planting to spruce; and those plantations receiving only manual release. Individual treatment importance rank was YEAR and PREP (27 percent), SPECIES (21 percent), and RELEASE (14 percent). All treatments combined accounted for 12 percent of the variation in wild sarsaparilla biomass.

Table 3.—*Mean and standard error estimates for herb, fern and fern ally, and low shrub species biomass (ovendry) in 53 conifer plantations near Isabella, Minnesota*

Species	Plantations	BIOMASS	
		Mean	Standard error
	Number	*Pounds/acre*	
Herbs			
Achillea Millefolium L.	1	0.01[1]	—
Actea rubra (Ait) Willd.	2	.14	0.13
Anaphalis margaritacea (L.). Benth.& Hook	7	.01	0
Aneomone quinquefolia	29	.07	.04
Antennaria spp. Gaertn.	4	.01	0
Apocynum androsaemifolium	15	4.09	.90
Aquilegia canadensis L.	1	.01	—
Aralia nudicaulis	44	7.23	1.17
Aster ciliolatus Lindl.	5	11.00	4.14
Aster macrophyllus	53	60.81	6.39
Aster umbellatus Mill.	1	1.29	—
Circaea canadensis Hill	1	.01	—
Clintonia borealis	39	9.63	1.35
Coptis groenlandica (Oeder) Fern.	10	.01	.01
Cornus canadensis	45	10.59	1.65
Cyperaceae	14	.30	.28
Epilobium angustifolium L.	9	.83	.25
Fragaria vesca	22	6.80	2.67
Fragaria virginiana	29	6.27	1.30
Galium triflorum Michx.	8	.09	.05
Goodyera repens (L.) R. Br.	1	.01	—
Gramineae	53	116.50	14.02
Hepatica americana (D.C.) Ker.	2	.01	0
Hieracium spp. L.	1	.01	—
Lactuca spp. L.	3	.01	0
Lathyrus ochroleucus	25	10.51	2.77
Lathyrus palustris	3	7.03	7.85
Lathyrus venosus	6	19.86	9.71
Lathyrus spp. L	3	3.61	.42
Linnaea borealis	30	7.24	1.19
Maianthemum canadense	48	3.44	.42
Melampyrum lineare Desr.	7	.01	0
Mitella nuda L.	1	.01	—
Moneses uniflora (L.) Gray	1	.01	—
Petasites palmatus (Ait.) Gray	1	.01	—
Polygala paucifolia	25	.01	.01
Polygonum cilinode Michx	4	.01	.01
Pyrola elliptica	1	2.56	—
Pyrola rotundifolia L	5	2.36	.77
Pyrola secunda L.	17	2.57	.43
Pyrola virens	8	1.92	.32
Pyrola spp. L.	8	2.15	.37
Senecio spp. L.	1	.01	—
Solidago spp. L.	12	.02	.01
Streptopus roseus	17	1.02	.73
Taraxacum officinale Weber.	1	.01	—
Trientalis borealis	19	.02	.01
Unidentified herbs	11	.01	0
Vicia americana Muhl	1	.01	—
Viola adunca	2	.62	.23
Viola spp. L.	22	.75	.13
Fernand fern allies			
Dryopteris spp. Adans.	3	.75	.45
Lycopodium annotinum L.	10	.01	0
Lycopodium clavatum L.	15	.18	.15
Lycopodium complanatum L.	8	.04	.03
Lycopodium lucidulum Michx.	2	.01	0
Lycopodium obscurum L.	14	.58	.57
Lycopodium spp. L.	1	.07	—
Pteridium aquilinum	37	106.88	15.98
Shrubs[2]			
Arctostaphylos uva-ursi	3	22.62	.75
Chimaphila umbellata	14	8.38	1.82
Comptonia peregrina	14	30.68	7.92
Diervilla Lonicera	49	38.89	5.44
Gaultheria hispidula	2	7.92	1.26
Gaultheria procumbens	17	25.66	6.27
Ledum groenlandicum Oeder.	4	8.05	7.76
Rubus pubescens	49	1.20	.33
Vaccinium angustifolium	49	15.29	3.42
Vaccinium myrtilloides	37	22.48	4.47
Total biomass[3]	53	389.39	32.03

[1]Mean for stands where species occurred in the sample.

[2]Does not include *Rosa acicularis* and *Rubus strigosus*, which were included within the tall shrub stratum.

[3]Mean of total biomass was calculated by summing raw biomass values for each species in each of the 53 plantations and dividing by 53. This value does not equal the sum of means from this table

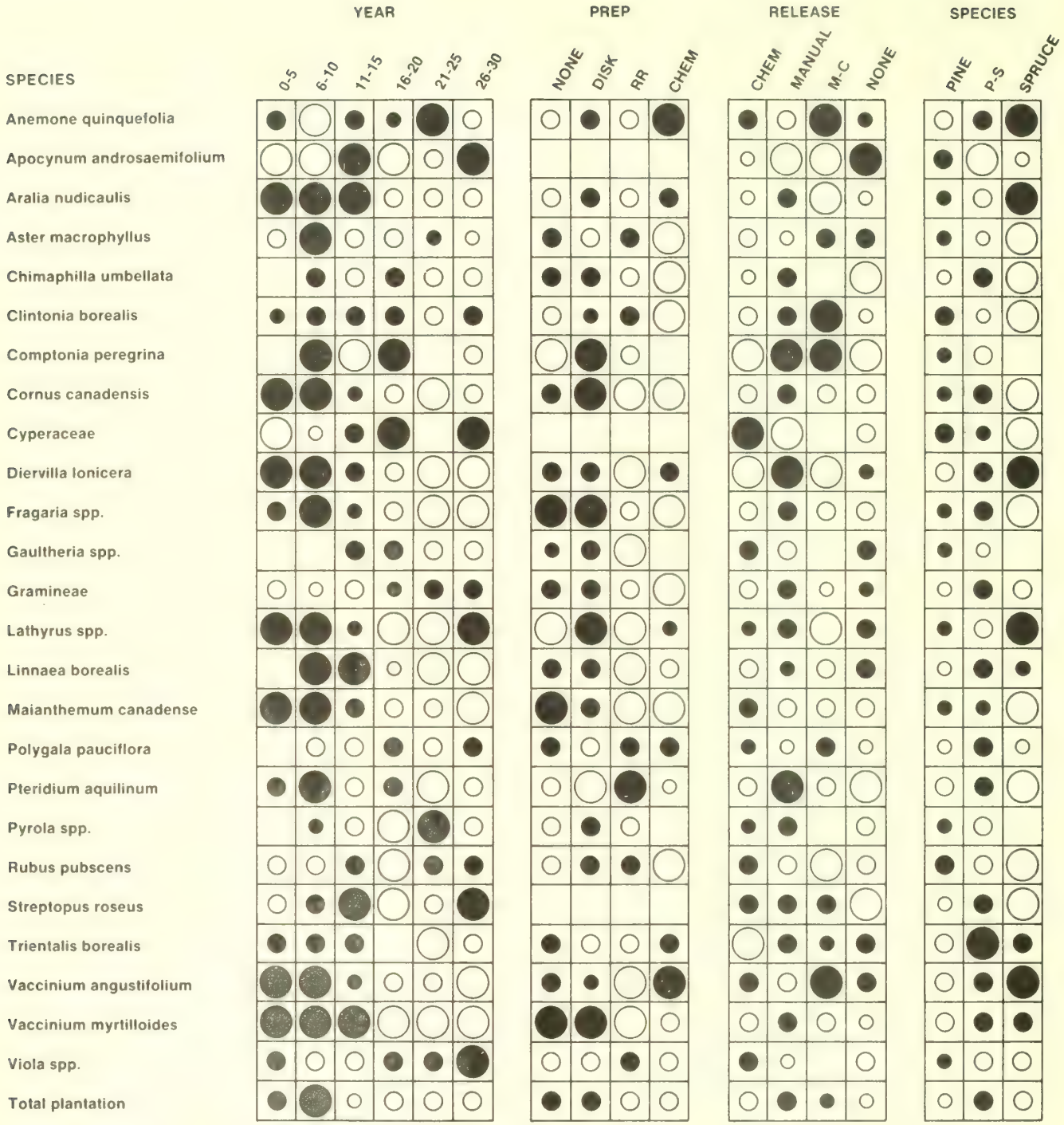

Figure 5.—*Diagrammatic representation of classification analysis results depicting the influence of silvicultural treatments on the major herb-low shrub layer species in conifer plantations near Isabella, Minnesota. Shaded circles represent a negative influence and open circles represent a positive influence. Degree of influence: small circle-slight; medium circle-average; large circle-strong. YEAR indicates the plantation age class; PREP-site preparation for planting (none, disking, rock-raking, or chemical); RELEASE-plantation release through manual, manual-plus chemical, chemical means, or no release; and species, plantation of red and/or jack pine, pine plus white spruce, or white spruce species only.*

Large-leaf aster

Aster is a rhizomatous herb that is found abundant in upland broadleaf and mixed conifer forests. It was included in samples from all plantations and in all treatment categories at a mean estimated biomass of 60 lbs/acre (table 3). Above-average biomass was associated with younger plantations (except those prepared by rock-raking); disked or chemically prepared plantations; those chemically or manually released; and plantations planted to spruce. Below-average biomass was associated with older pine plantations, especially those receiving no site preparation or release; sites prepared by rock-raking; and plantations receiving manual plus chemical release. Individual treatment importance ranked YEAR (30 percent), PREP (20 percent) RELEASE (18 percent), and SPECIES (18 percent); and the combination YEAR-PREP-RELEASE accounted for 20 percent of the variation in aster biomass.

Pipsissewa

Pipsissewa (prince's pine) is a somewhat ligneous plant with spreading stems commonly found in dry coniferous forests. It occurred in 14 of the plantations at a mean estimated biomass of 8 lbs/acre (table 3). It was not sampled in the 1- to 5-year-old plantations or within the manual plus chemical release category. More biomass was associated with older plantations with no record of release and younger plantations chemically prepared for planting to spruce. Treatments associated with reduced pipsissewa biomass were manual plantation release; disk or no site preparation; and younger plantations (except those planted to spruce). Individual treatment importance ranked RELEASE (61 percent), PREP (39 percent), SPECIES (38 percent), and YEAR (23 percent). The treatments YEAR-RELEASE-SPECIES combined accounted for 65 percent of the variation in this species' biomass.

Clinton's lily

Clintonia borealis (Ait.) Raf. is a common perennial herb primarily found in rich moist woods and wooded bogs. It was found in 39 of the sample plantations at a mean estimated biomass of 10 lbs/acre (table 3). Its biomass was positively associated with sites chemically prepared for planting to spruce and to a lesser extent older plantations with no recorded site preparation that were later chemically released. Negative treatment influences on biomass were older plantations prepared by disking; younger plantations prepared by rock-raking and planted to pine; and plantations released by either manual or manual plus chemical means. Individual treatment importance ranked PREP (39 percent), YEAR (34 percent), SPECIES (31 percent), and RELEASE (23 percent). All treatments combined accounted for 27 percent of the variability in biomass. ANOVA indicated significant interactions among both YEAR-PREP-RELEASE and YEAR-RELEASE-SPECIES treatment combinations.

Sweet fern

Sweet fern is a medium-sized shrub commonly found in dry sandy or rocky pine forests. It occurred in 14 of the plantations with a mean estimated biomass of 31 lbs/acre (table 3). It did not occur in samples from the 1- to 5- and 21- to 25-year-old plantations nor in plantations chemically prepared for planting to spruce. Above-average biomass was related to plantations that had received no site preparation and no release and sites prepared by rock-raking and planted to pine-spruce species. In addition to not occurring in the two age-class and spruce plantations mentioned above, below-average biomass was associated with disk site preparation and chemical plantation release. Sweet fern is intermediate in susceptibility to 2,4-D and highly susceptible to 2,4,5-T (Bovey 1977). Individual treatment importance ranked PREP (54 percent), YEAR (26 percent), RELEASE (24 percent), and SPECIES (17 percent); the combination of PREP, RELEASE, SPECIES accounted for 49 percent of the variation in biomass.

Bunchberry

Cornus canadensis L. is a herbaceous colonial plant that spreads from rhizomes and is abundant in moist, acid, forests and bogs. It occurred in the samples from 45 plantations at a mean estimated biomass of 11 lbs/acre (table 3). Its biomass values were positively associated with older plantations; plantations that received rock-raking as a site preparation treatment; and plantations with no record of release. More biomass was also associated with plantations chemically prepared for planting to spruce. Bunchberry biomass was reduced in younger plantations; older pine plantations established without site preparation or by disking; and plantations that received manual or manual plus chemical release. Bunchberry is resistant to 2,4-D and intermediatly resistant to 2,4,5-T (Bovey 1977). Individual treatments ranked YEAR (21 percent), PREP (10 percent), SPECIES (8 percent), and RELEASE (3 percent) in importance. Together, YEAR-PREP-RELEASE accounted for 15 percent of the variation in biomass. In a 3-way ANOVA, RELEASE and SPECIES showed a statistically significant level of interaction.

Sedges

The combination YEAR (62 percent), SPECIES (40 percent), and RELEASE (34 percent) accounted for

71 percent of the variation in sedge biomass. Sedges were found in 14 plantations and were estimated to have a mean biomass of less than 1 lb/acre (table 3). More biomass was associated with the youngest plantations (1 to 10 years old); plantations chemically prepared for planting to spruce; and plantations that received manual release or where no release was recorded. Less biomass was associated with older pine plantations that received chemical release. A 3-way ANOVA indicated YEAR, RELEASE, and SPECIES to all be significant, with a significant interaction between YEAR and RELEASE.

Bush honeysuckle

Bush honeysuckle is an erect low shrub common in mesic to dry open woods, clearings, and rocky places. It was found in 49 of the plantations at a mean estimated biomass of 39 lbs/acre (table 3). Above-average biomass was associated with older pine plantations; chemical or manual plus chemical release; and rock-rake site preparation treatment. Below-average biomass was associated with younger plantations; plantations given a manual release or where no release was recorded; and those sites chemically prepared for planting to spruce. Bush honeysuckle is susceptible to foliar applied 2,4-D (Bovey 1977). Treatment influence ranked YEAR (28 percent), RELEASE (22 percent), PREP (21 percent), and SPECIES (18 percent), with 24 percent of the biomass variation accounted for by the combination of YEAR-PREP-RELEASE treatments. A 3-way ANOVA indicated a significant interaction between RELEASE and SPECIES.

Strawberry

Strawberries (*Fragaria vesca* L. and *F. virginiana* Duchesne.) are perennial herbs that spread by stolons. Biomass values for both species were combined for this ANOVA and MCA analysis. They were found in 22 and 29 of the plantations, respectively, with mean estimated biomass values of 7 and 6 lbs/acre (table 3). More biomass was associated with older plantations that had no record of release or that had been chemically released; plantations with rock-rake site preparation; and sites chemically prepared for planting to spruce. Less biomass was associated with plantations that had been given manual or manual plus chemical release; plantations with no site preparation or disk site preparation; and sites planted to pine-spruce combinations. Treatment ranked RELEASE (32 percent), PREP (28 percent), SPECIES (24 percent), and YEAR (15 percent) in importance individually, and YEAR-PREP-RELEASE combined accounted for 28 percent of the variation in strawberry biomass. PREP and RELEASE were statistically significant in 3-way ANOVAs, and significant interaction was present between YEAR and RELEASE, YEAR and SPECIES, and RELEASE and SPECIES.

Snowberry and Wintergreen

Snowberry *Gaultheria hispidula* (L.) Muhl. is a creeping shrub of bogs and moist coniferous forests; and wintergreen is a woody low shrub common in rocky or sandy coniferous forests with leafy erect stems from horizontal rhizomes. The two species were combined for ANOVA and MCA analysis. Snowberry was sampled in only 2 plantations, while wintergreen occurred in 17 plantation samples. Mean estimated biomass was 8 lbs/acre for snowberry and 26 lbs/acre for wintergreen (table 3). Rock-rake site preparation, manual plantation release, and older plantations were related to increased biomass; disk site preparation, no record of release, and younger plantations were related to decreased biomass. Treatment importance rank was PREP (50 percent), RELEASE (48 percent), YEAR (45 percent), and SPECIES (2 percent); and together they accounted for 41 percent of the variation in estimated biomass.

Grasses

All grass species were combined for sampling and analysis. Grasses occurred in the samples from all plantations and treatment categories and were the leading contributor to the biomass of the herb-low shrub stratum with a mean value of 116 lbs/acre (table 3). Above average biomass was associated with plantations on rock-raked sites; sites chemically prepared for planting to spruce, young plantations, and chemically released plantations. Below-average biomass was associated with older plantations that had no site preparation or had been prepared by disking, plantations with only manual release, and sites planted to a pine-spruce combination. Individual treatments ranked PREP (41 percent), YEAR (35 percent), RELEASE (29 percent), and SPECIES (27 percent) in importance; while YEAR-PREP-RELEASE combined accounted for 23 percent of the variation in estimated grass biomass. A 3-way ANOVA indicated significant interaction effects between YEAR and SPECIES, and RELEASE and SPECIES.

Wild pea

The *Lathyrus* species, *Lathyrus ochroleucus* Hook., *L. palustris* L., and *L. venosus* Muhl., were combined for ANOVA and MCA analysis. These herbaceous rhizomatous perennials are common to abundant in dry upland forests, moist woods and thickets, and wet meadows and swamps. They occurred in 23, 3, and 6 plantations, respectively, at mean estimated biomass values of 11, 7, and 20 lbs/acre (table 3). More biomass

was found in 15- to 20-year-old pine-spruce plantations; plantations with no site preparation; those prepared by rock-raking, and plantations that received manual plus chemical release. Less biomass was found in younger plantations prepared by disking; older plantations prepared by disking; sites chemically prepared for planting to spruce; and plantations manually released or with no record of release. Individual treatment importance ranked YEAR (52 percent), SPECIES (49 percent), PREP (36 percent), and RELEASE (24 percent); and YEAR-PREP-RELEASE combined accounted for 47 percent of the variation in biomass. The independent variables YEAR, PREP, and SPECIES were significant as determined by 3-way ANOVA, and a significant interaction effect was also present.

Twin flower

Twin flower is a trailing, creeping, slightly woody evergreen plant frequently found in moist to dry forests. It was present in 30 of the plantation samples with a mean estimated biomass of 7 lbs/acre (table 3). Above-average biomass values were associated with older plantations; plantations with manual and manual plus chemical release; plantations with rock-rake site preparation; and pine plantations. Below-average biomass values were associated with younger plantations (it was not included in the samples from the most recent sites); plantations with no record of release; plantations with disk or no site preparation; and areas planted to spruce. Importance of treatments ranked YEAR (53 percent), RELEASE (50 percent), SPECIES (17 percent), and PREP (16 percent); YEAR-PREP-RELEASE combined accounted for 56 percent of the biomass variation. This combination in a 3-way ANOVA was also statistically significant for main effect and YEAR as an independent variable.

False lily-of-the-valley

Maianthemum canadense Desf. is a small, common perennial herb that forms mats from creeping rhizomes. It was recorded in the samples from 48 of the plantations with a mean estimated biomass of 3 lbs/acre (table 3). Above-average biomass was related to plantations with no record of release or only manual release; rock-rake prepared sites; and sites chemically prepared for planting to spruce. Below-average biomass was related to younger plantations; plantations that were chemically released, disked, or received no site preparation; and spruce-pine plantations. Individual treatments ranked RELEASE (41 percent), PREP (34 percent), YEAR (26 percent), and SPECIES (7 percent) in importance, with 36 percent of the variation accounted for by YEAR-PREP-RELEASE. A 3-way ANOVA indicated the combination YEAR-PREP-RELEASE was significant, as were variables PREP and RELEASE.

Fringed milkwort

Polygala pauciflora Willd. is a widespread but uncommon prerennial plant from slender underground rhizomes found on light sandy soils in mesic to moist woods. It was included within the sample of 25 plantations with a mean biomass of less than 1 lb/acre (table 3). Above-average biomass values were associated with 21- to 25-year-old plantations prepared for planting by disking and with no record of release. Below-average biomass values were associated with pine-spruce plantations prepared by rock-raking and plantations that received manual plus chemical release. Individual treatments ranked YEAR (61 percent), PREP (33 percent), RELEASE (17 percent), and SPECIES (17 percent); YEAR-PREP-RELEASE combined accounted for 57 percent of the variation in estimated biomass.

Bracken fern

Bracken is a common fern with large deciduous fronds from stout, spreading rhizomes. It occurred in 37 of the plantations and in all treatment categories. Its mean estimated biomass was 107 lbs/acre (table 3). Above average biomass was associated with older plantations prepared by disking that received no release. Below-average biomass was associated with younger plantations; rock-rake site preparation; manual release; and pine-spruce plantings. Individual treatment ranked PREP (40 percent), RELEASE (38 percent), YEAR (24 percent), and SPECIES (6 percent), with YEAR-PREP-RELEASE combined accounting for 45 percent of the variation in estimated biomass. A 3-way ANOVA indicated that YEAR, PREP, and RELEASE were all significant independent variables.

Shinleaf

The various shinleafs are small perennial evergreen plants from spreading rhizomes commonly found in dry to moist upland forests. They were included within samples in from 1 (*Pyrola elliptica* Nutt.) to 8 (*P. virens* Schweigg.) plantations with a mean estimated biomass of about 2-3 lbs/acre (table 3). All shinleaf species were combined for ANOVA and MCA. All combinations of YEAR-PREP-RELEASE-SPECIES were significant in 3-way ANOVAS, with YEAR a significant independent variable. Individually, YEAR was the most important treatment (61 percent), followed by RELEASE (31 percent), PREP (29 percent), and SPECIES (2 percent). All treatments combined accounted for 46 percent of the variation in estimated shinleaf biomass. Above average biomass was associated with 15- to 20-year-old

plantations; plantations with no record of release; plantations with no site preparation or rock-rake preparation; and sites planted to pine. Below-average biomass was associated with 20- to 25-year-old plantations; plantations manually released; and sites prepared by disking.

Dewberry

Dewberry, a perennial low shrub from profusely creeping stolons, is commonly found in bogs, moist woods, and damp slopes. It was included within the sample of 49 of the plantations and in all treatment categories. Its mean estimated biomass was about 1 lb/acre (table 3). Above-average biomass was associated with sites prepared with chemicals for planting to spruce and plantations released by manual plus chemical treatments. Below-average biomass was found in older pine plantations prepared for planting by disking and later chemically released. Dewberry is intermediate to resistant to foliar applied 2,4-D and intermediate in susceptibility to 2,4,5-T (Bovey 1977). Individual treatments ranked SPECIES (30 percent), both YEAR and PREP (29 percent), and RELEASE (26 percent) in importance; the combination SPECIES-YEAR-RELEASE accounted for 24 percent of the variation in dewberry biomass.

Twisted stalk

Streptopus roseus Michx. is a perennial herb from slender elongated rhizomes commonly found in coniferous and broadleaf mesic to moist forests. It occurred in the samples of 17 plantations with an estimated 1 lb/acre biomass (table 3). More biomass was associated with 5- to 25-year-old plantations that had no record of release. Less biomass was associated with all types of release; pine-spruce planting combinations; and 5- to 15-year-old plantations. Individual treatments ranked YEAR (60 percent), RELEASE (27 percent), and SPECIES (25 percent) in importance. PREP could not be tested in this case. The combination of treatments accounted for 50 percent of the variation in twisted stalk biomass. YEAR and RELEASE were statistically significant as independent variables in a 3-way ANOVA, and there was also significant interaction between them.

Star flower

Star flower is a low perennial herb from slender rhizomes that is widespread and common in mesic and moist woods. It was included in the sample from 19 plantations at a mean estimated biomass of less than 1 lb/acre (table 3). Above-average biomass was associated with older pine plantations; disked or rock-raked prepared sites; and chemical release. Below-average biomass was associated with younger plantations; no site preparation for planting; manual or manual plus chemical release; and planting to pine-spruce combinations. Importance of treatments ranked YEAR (67 percent), PREP (34 percent), SPECIES (21 percent), and RELEASE (20 percent). The combination of YEAR-SPECIES-RELEASE accounted for 72 percent of the variation in star flower biomass.

Late sweet blueberry

Blueberry is a colonial low shrub spreading from a stoloniferous base commonly found in dry rocky or sandy woods. It was included in samples from 49 of the plantations with a mean estimated biomass of 15 lbs/acre (table 3). Higher biomass values were found in older pine plantations; those prepared by rock-raking; and those manually released. Lower biomass values were found in younger plantations, especially those prepared chemically for planting to spruce, and plantations that received manual plus chemical or only chemical release. Blueberries are intermediate to resistant to foliar-applied 2,4-D and intermediate in resistance to foliar-applied 2,4,5-T (Bovey 1977). Individual treatment importance ranked YEAR (51 percent), PREP (39 percent), SPECIES (35 percent), and RELEASE (31 percent). The combinations YEAR-PREP-RELEASE and YEAR-RELEASE-SPECIES were statistically significant in a 3-way ANOVA and accounted for 39 and 37 percent of the variation in blueberry biomass, respectively.

Velvet-leaf blueberry

Velvet-leaf blueberry is a perennial colonial low shrub common from lowland to granite outcrops. It occurred in 37 plantations at a mean estimated biomass of 23 lbs/acre (table 3). More biomass was found in older pine plantations; rock-raked sites; plantations that received manual plus chemical release; or those that had no record of release. Less biomass was found in young plantations; spruce or pine-spruce plantings; disked sites; sites that received no preparation; and sites with manual release. Individual treatments ranked YEAR (46 percent), both PREP and SPECIES (31 percent), and RELEASE (26 percent); the combination YEAR-PREP-RELEASE accounted for 42 percent of the biomass variation. A 3-way ANOVA showed both YEAR and PREP to be statistically significant independent variables.

Violets

The *Viola* species (mostly *V. adunca* Sm.) are small rhizomatous and stoloniferous herbs common in open rocky to sandy forests. Violets were recorded in the samples from 22 plantations with a mean estimated biomass of almost 1 lb/acre (table 3). More biomass

was associated with 6- to 15-year-old pine-spruce plantations; spruce plantations prepared by chemical site preparation; and plantations with no release. Less biomass was found in very young plantations; older pine plantations that received chemical release; and rock-raked sites. Individual treatments ranked YEAR (42 percent), RELEASE (36 percent), PREP (39 percent), and SPECIES (26 percent) in importance; the YEAR-PREP-RELEASE combination accounted for 31 percent of the variation in violet biomass.

Plantation total herb and low shrub biomass

Mean total herb, fern and fern ally, and low shrub biomass was estimated at 389 lbs/acre. Above-average biomass was associated with older pine plantations receiving chemical release; plantations given rock-raked site preparation; and sites chemically prepared for planting to spruce. Below-average biomass was associated with more recent plantations; plantations receiving no site preparation or disk site preparation; and plantations with manual release. No treatment explained a statistically significant amount of the variation in total plantation biomass, although a statistically significant interaction was found between YEAR and RELEASE and between RELEASE and SPECIES. YEAR was the most important individual treatment (30 percent), followed by RELEASE (20 percent), PREP (9 percent), and SPECIES (8 percent); YEAR-PREP-RELEASE combined accounted for 22 percent of the variation in total biomass.

CONCLUSIONS

Most of the undergrowth species responses to silvicultural practices found in this study are consistent with the little we know about their ecological requirements. Biologists and others have expressed concern that successful establishment of conifer plantations has a detrimental effect on the other forest flora (Swindel *et al.* 1983). This was not the case in this study, although there undoubtedly was a good deal of initial disturbance and disruption of the understory flora by the silvicultural practices. But it made a rapid recovery, which is enhanced by the clonal nature and presence of underground structures that permit vegetative reproduction of many of the major species in these plantations. The silvicultural goal of successful establishment and regeneration of conifer stands was met for these plantations, yet the stands contained undergrowth layers similar in species composition and standing crop (biomass) to those naturally regenerated after disturbance. The undergrowth layers were also similar to those found in mature conifer forest communities of the area.

Competing forest flora in conifer plantations is considered to have a negative effect on conifer growth, especially for the first few years (Newton 1981). The older Isabella plantations seem to be producing as much tree biomass as other similar natural and planted stands of the region. However, most studies of plantations do not report the tree biomass of species other than those planted. Restricting evaluation of the Isabella plantations tree biomass to only the species planted would show them to be producing less than other pine plantations cited—pine contributed only 50 to 85 percent of the tree biomass in the older plantations. On the other hand, the plantations for which only pine biomass is reported are probably not pure pine stands unless they were intensively managed. If not, the reported biomass of those plantations, at least for the tree stratum, is conservative. The presence of considerable nonpine tree biomass, while perhaps economically undesirable, is a positive ecological factor because it fulfills the requirement of maintaining species diversity within these plantations.

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APPENDIX

The Appendix contains detailed tabular information on species biomass estimates by treatment categories and the analysis of variance results for within treatment categories.

Appendix table 1.--Herb-low shrub layer biomass (ovendry), standard error of the mean, and number of plantations for each establishment-period (YEAR) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the P = 0.05 probability level[1/]

Species	0-5 Years			6-10 Years			11-15 Years			16-20 Years			21-25 Years			26-30 Years			ANOVA F Ratio	ANOVA Probability
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N		
	- - -

(Appendix table 1 continued)

Species	0-5 Years			6-10 Years			11-15 Years			16-20 Years			21-25 Years			26-30 Years			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	- - -

Appendix table 2.--Herb-low shrub layer biomass (ovendry), standard error of the mean, and number of plantations for each site-preparation (PREP) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the P = 0.05 probability level[1/]

Species	None			Disk			Rockrake			Chemical			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	- - -

(Appendix table 2 continued)

Species	None			Disk			Rockrake			Chemical			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Proba-bility
	- - -

Appendix table 3.--Herb-low shrub layer biomass (ovendry), standard error of the mean, and number of plantations for each release (RELEASE) category for nifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the P = 0.05 probabilit, level[1/]

	Chemical			Manual			Manual-chemical			No record			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	Pounds/acre													
Herbs														
Achillea Millefolium										0.01	-	1		
Actea rubra				0.26	-	1				.01	-	1		
Anaphalis margaritacea	0.01	0	3	.01	0	2				.01	0	2		
Anemone quinquefolia	.01	0	8	.11	.08	13	0.01	0	2	.09	.07	6	0.436	0.729
Antennaria spp.	.01	-	1							.01	0	3		
Apocynum androsaemifolium	4.97	1.41	6	4.38	2.20	4	.90	-	1	3.28	1.69	4	.430	.736
Aquilegia canadensis				.01	-	1								
Aralia nudicaulis	4.83	1.27	13	7.83	2.19	19	7.40	3.18	2	9.22	2.47	10	.660	.581
Aster ciliolatus	4.57	2.21	3	21.91	-	1				19.40	-	1		
Aster macrophyllus	65.67	10.23	17	65.17	11.58	21	60.10	38.27	3	46.46	10.93	12	.489	.692
Aster umbellatus	1.29	-	1											
Circaea canadensis										.01	-	1		
Clintonia borealis	11.53	2.28	11	8.81	1.54	20	2.30	-	1	10.07	5.12	7	.490	.692
Coptis groenlandica				.01	0	7				.01	0	3		
Cornus canadensis	8.24	2.35	13	10.65	2.46	20	16.45	13.07	3	11.91	3.69	9	.504	.682
Cyperaceae	.06	.05	4	.98	.97	4				.01	0	6	1.255	.323
Epilobium angustifolium	1.22	.49	4	.34	.52	2	.16	.34	2	.86	-	1		
Fragaria vesca	4.91	.96	7	2.71	.67	9				15.12	9.39	6		
Fragaria virginiana	9.09	2.99	11	4.47	1.02	10	2.66	.92	2	5.30	2.16	6	1.333	.275 [2/]
Galium triflorum	.13	.08	5	.01	-	1				.02	.01	2		
Goodyera repens				.01	-	1								
Gramineae	160.46	30.96	17	85.62	14.96	21	90.29	21.77	3	114.83	31.28	12	1.845	.151
Hepatica americana	.01	0	2											
Hieracium spp.				.01	-	1								
Lactuca spp.	.01	-	1							.01	0	2		
Lathyrus ochroleucus	15.85	6.18	10	5.46	2.44	8	12.58	10.16	2	7.07	1.87	5		
Lathyrus palustris	4.36	3.56	2							14.85	-	1		
Lathyrus venosus	8.36	3.85	3	32.42	31.12	2	26.29	-	1				.318	.812 [2/]
Lathyrus spp.	3.20	0.15	2							4.42	-	1		
Linnaea borealis	4.58	1.50	7	9.78	1.74	14	3.73	1.45	3	6.19	3.63	6	1.505	.236
Maianthemum canadense	2.42	.87	15	4.33	.62	20	2.07	.66	2	3.47	.64	11	1.473	.235
Melampyrum lineare	.01	-	1	.01	0	4				.01	0	2		
Mitella nuda	.01	-	1											
Moneses uniflora										.01	-	1		
Petasites palmatus										.01	-	1		
Polygala paucifolia	.01	0	8	.01	0	11	.01	-	1	.01	0	5	.284	.836
Polygonum cilinode	.01	-	1	.01	-	1	.01	-	1	.01	-	1		
Pyrola elliptica				2.56	-	1								
Pyrola rotundifolia	.10	-	1	3.26	.84	3				1.93	-	1		
Pyrola secunda	2.19	.55	5	2.02	.97	6				3.43	.55	6		
Pyrola virens	1.93	-	1	1.92	.54	5				1.93	0	2	1.017	.372 [2/]
Pyrola spp.	2.83	.90	2	1.39	.65	3				2.47	.29	3		
Senecio spp.										.01	-	1		
Solidago spp.	.04	.03	4	.01	0	4				.01	0	4		
Streptopus roseus	.61	.46	4	1.39	1.24	10	.08	-	1	.46	.16	2	.109	.954
Taraxacum officinale	.01	-	1											
Trientalis borealis	.01	0	5	.03	.02	9	.01	-	1	.01	0	4	.267	.848

(Appendix table 3 continued on next page)

(Appendix table 3 continued)

Species	Chemical			Manual			Manual-chemical			No record			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Proba-bility
	Pounds/acre													
Unidentified spp.	.01	0	4	.01	0	3				.01	0	4		
Vicia americana										.01	-	1		
Viola adunca				.62	.23	2								
Viola spp.	.80	.24	8	.55	.17	10				1.11	.34	4	1.402	.268[2/]
Fern and fern allies														
Dryopteris spp.	1.68	-	1	.28	-	1				.28	-	1		
Lycopodium annotinum	.01	-	1	.01	0	2				.01	-	1		
Lycopodium clavatum	.01	0	5	.36	.34	7	.26	-	1	.01	0	3	.372	.775
Lycopodium complanatum	.01	0	3	.01	0	4				.26	-	1		
Lycopodium lucidulum	.01	-	1							.01	-	1	1.586	.248[2/]
Lycopodium obscurum	.01	0	7	1.61	1.59	5				.01	0	2	.895	.436
Lycopodium spp.							.07	-	1					
Pteridium aquilinum	131.00	27.09	13	79.81	25.55	15	180.59	155.02	2	99.01	15.89	7	1.058	.380
Shrubs														
Arctostaphylos uva-ursi	23.37	-	1	22.25	1.12	2								
Chimaphila umbellata	8.92	3.29	4	5.21	1.16	7				15.08	5.90	3	2.868	.100
Comptonia peregrina	30.11	16.21	3	35.95	15.83	6	11.95	6.80	2	33.21	14.90	3	.282	.838
Diervilla lonicera	45.10	9.18	15	34.49	10.14	19	47.20	11.13	3	36.01	10.59	12	.275	.843
Gaultheria hispidula				6.65	-	1				9.18	-	1		
Gaultheria procumbens	15.37	3.74	5	36.82	10.45	9				9.34	3.85	3	1.942	.176[2/]
Ledum groenlandicum	.01	-	1	16.08	15.22	2				.01	-	1		
Rubus pubescens	1.45	.83	15	.95	.40	21	3.82	3.28	2	.84	.28	11	1.063	.374
Vaccinium angustifolium	11.04	3.80	14	22.96	7.08	21	1.70	1.20	3	9.74	3.51	11	1.426	.248
Vaccinium myrtilloides	13.84	3.70	14	33.08	10.23	14	41.71	-	1	16.62	5.60	8	1.540	.222
Plantation total biomass[3/]	465.17	55.07	17	371.85	55.95	21	395.49	172.77	3	357.41	54.92	12	.665	.577

1/ Based on Student-Newman-Keuls test of those means indicated as significantly different by ANOVA.

2/ For some ANOVA's the following species were combined: Fragaria vesca and F. virginiana; all Lathyrus species; Lycopodium annotinum, L. complanatum, L. lucidulum, and L. spp.; all Pyrola species, Viola species, and Gaultheria species.

3/ Total biomass in the herbaceous and low shrub layer except for Rosa acicularis and Rubus strigosus, which were sampled and

Appendix table 4.--Herb-low shrub layer biomass (ovendry), standard error of the mean, and number of plantations for each species planted (SPECIES) category for conifer plantations near Isabella, Minnesota. Means in a row followed by the same letter do not differ at the P = 0.05 probability level[1/]

Species	Pine			Pine & spruce			Spruce			ANOVA F Ratio	ANOVA Probability
	Mean	SE	N	Mean	SE	N	Mean	SE	N		
	- - -

(Appendix table 4 continued)

Species	Pine			Pine & spruce			Spruce			ANOVA	
	Mean	SE	N	Mean	SE	N	Mean	SE	N	F Ratio	Probability
	- - -

Ohmann, Lewis F.
Biomass in conifer plantations of northeastern Minnesota. Res.Pap. NC-247. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 1984. 25 p.

Provides biomass (pounds/acre) estimates for vegetative strata and herb-low shrub species for 53 conifer plantations in northeastern Minnesota. The estimates are analyzed by plantation age and silvicultural practices used to establish and release the plantations.

KEY WORDS: Site preparation, plantation release, silviculture, herbicide, biomass estimation.

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The Legal System, The U.S. Forest Service, and Human-Caused Wild Fires

Linda R. Donoghue and Donna M. Paananen

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PREFACE

Although law enforcement has traditionally played an important role in the USDA Forest Service and, from a wildfire standpoint, has been widely recognized as one of the three "E's" of fire prevention (enforcement, engineering, education), no one has examined in detail how law enforcement is used to prevent or control wildfire ignitions. Most people assume that law enforcement is a relatively simple, straightforward activity that requires little in the way of additional understanding or enlightenment. We thought so too when we first began this project. Our primary objective was to describe the enforcement component of wildfire prevention so that we could develop a model of it, quantify enforcement activities, and eventually measure the impact of key activities on wildfire ignitions. Little did we know how complex and time-consuming this task would be.

As we began our description of law enforcement, we realized immediately that it was only part of the picture, that we could not treat it independently of other elements such as the law, the courts, and the civil and criminal processes. Consequently, we took a step back and described the American legal system (a much larger task) and its relations to the USDA Forest Service and wildfire ignitions.

We encountered numerous problems along the way, problems that any serious student of the subject will also find:

- Almost none of the literature treats enforcement and other aspects of the legal system from a "systems" perspective, even though words such as "criminal justice system" are used repeatedly in the titles and texts.
- The literature is full of conflicting viewpoints, classification systems, and approaches to the subject. This reflects, in part, the vast nature and complexity of the material itself.
- It was difficult to find clear, lucid, well-organized texts (which are possible even if the subject matter is complex), and we were repeatedly frustrated with poorly defined terms and concepts.

Recognizing these problems, we decided to approach the subject from a systems point of view rather than from a traditional perspective. The systems approach is holistic—it takes the big picture of something and breaks it down into its individual component parts. On the other hand, the traditional approach looks at the individual components first and then assembles them into a larger picture, under the assumption that you can explain an entire system by summing its individual parts. This latter method is often inadequate when explaining a complex phenomenon such as the American legal system because, as is often the case, the whole proves to be *greater* than the sum of its individual parts. We opted for the systems approach, believing that it would give us a better understanding of the American legal system than would the traditional method.

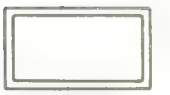
We identified the major components and subcomponents of the legal system, described the structure of the system, particularly the relations between the components and subcomponents (a discussion of these relations is found at the beginning of each major section of the paper), and discussed the ways in which the system processes its human inputs and outputs via the civil and criminal processes. In so doing, we tried to draw together and present the common threads (ideas and concepts) running through the enormous variety of literature we reviewed and to define clearly our terms and concepts both in the text and in the glossary.

Some may argue that in taking this approach, we've lost the substance. But, our objective in writing this paper was not to supply a comprehensive, in-depth explanation of the legal system but rather to explain the system well enough and simply enough so that people new to the subject—modelers, scientists, or land managers—can understand and apply it in their daily work, whether it's developing simulation models or wondering how a claim is settled before it gets to court. For those readers desiring in-depth information about a particular subject, we've included a list of recommended readings at the end of the publication.

Finally, we hope that the information presented here, some of which is old and some of which we document for the first time, piques the interest of our readers. We hope that in so doing, some readers will be stimulated to pursue additional research on the American legal system and wildfire ignitions and that others, having the basic knowledge and understanding of the system and its ties to wildfire prevention, will use it in a fruitful and efficient manner.

FLOWCHART KEY

Major components of the American legal system



Subcomponents of the American legal system

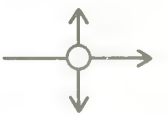
People or activities of people

Flow of people through the American legal system

Interactions between components and subcomponents of the legal system; interactions between components and subcomponents of the legal system and people and/or activities of people

Two flow lines that do not connect

Branch point, indicating a flow in more than one direction



An infinite source or an infinite sink

Connector, indicating flow to widely separated parts of a diagram

System outputs (O/S is an abbreviation for "out-of-system").

CONTENTS

Page

A GENERAL OVERVIEW OF THE AMERICAN LEGAL SYSTEM 1
LAW 3
Unlegislated Laws 3
Legislated Laws 5
The Forest Service and Law 5
LAW ENFORCEMENT AND ENFORCEMENT AGENCIES 6
Law Enforcement Agencies 9
Forest Service Law Enforcement 9
Law Enforcement Personnel 10
Law Enforcement Agencies 11
COURTS 12
Structure and Jurisdiction of Federal and State Court Systems 12
The Forest Service and the Courts 14
CIVIL PROCESS 15
The Forest Service and the Civil Process 16
Settlement Before Cases Reach Court: Demand-for-Payment Process 17
CRIMINAL PROCESS 19
The Forest Service and the Criminal Process 20
FOREST SERVICE LAW ENFORCEMENT, WILDFIRE VIOLATIONS, AND FIRE PREVENTION 21
Overview 21
The Role of Law Enforcement in Wildfire Violations 24
The Role of Law Enforcement in Wildfire Prevention 25
REFERENCES 26
RECOMMENDED READINGS 27
APPENDIX I.—STATUTES, REGULATIONS, ORDERS, AND NOTICES 28
A.—The United States Code, the United States Statutes at Large, and the United States Code Annotated 28
B.—Forest Service Regulations, Orders, and Notices 29
C.—Procedures for Formulating Federal Regulations 29
APPENDIX II.—FEDERAL WILDFIRE PROTECTION ACTS 29
APPENDIX III.—IMPRISONMENT 30
APPENDIX IV.—COURT JURISDICTION 30
APPENDIX V.—THE CIVIL PROCESS 30
APPENDIX VI.—THE CRIMINAL PROCESS 36
APPENDIX VII.—SIMILARITIES AND DIFFERENCES BETWEEN THE CIVIL AND CRIMINAL PROCESSES 44
APPENDIX VIII.—ABBREVIATIONS AND GLOSSARY 46
INDEX 53

THE LEGAL SYSTEM, THE U.S. FOREST SERVICE, AND HUMAN-CAUSED WILDFIRES

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Ninety-one percent of all wildfires occurring in the United States are caused by human activities. From 1974 through 1978, an average of 128,092 fires burned 1,814,943 acres of forest and other protected land (USDA Forest Service 1972-1980). In Region 9 alone (the 20 north-central and northeastern States) the estimated costs each year of presuppression, suppression, and damage resulting from fires totaled more than $50 million.[1] Such costs are a major concern to wildland agencies. Any reduction in the number of fire starts would reduce the wasteful destruction of our nation's forests, maintain our wildland resources, and lessen (or at least hold static) the costs to American taxpayers.

Information and education programs, such as Smokey Bear, have been helpful in reducing human-caused wildfires, but they cannot do the whole job. Professionals in land management agencies must also supplement public education with other programs which, when properly understood and applied, could significantly reduce the number of fire ignitions in the forest environment.

Using the legal system to prevent and control human-caused wildfires is one way of supplementing education programs. When correctly utilized, the legal system may help persuade or control people unaffected by more indirect measures (such as education and information programs). For example, people violating fire laws can be fined or imprisoned for breaking the law. Consequently, if used in fire prevention efforts, the legal system could benefit land management agencies.

Whether or not such use of the legal system is beneficial, however, depends, in part, on what wildland managers know about the system and how they use it to prevent human-caused wildfires. In many instances, they do not fully utilize the system because they don't understand it, or they believe it's too complicated and time-consuming to access on a regular basis.

In an effort to alleviate these problems, we will (1) examine the American legal system in general, defining and describing major components and interactions of the system; (2) describe in greater detail the relations and interactions between the Forest Service and the legal system components and processes; (3) discuss how individuals enter, move through, and leave the legal system; and (4) evaluate how the Forest Service uses the legal system to repress wildfire offenses.

A GENERAL OVERVIEW OF THE AMERICAN LEGAL SYSTEM

The American legal system, as we see it, is a set of four interrelated components—legislative groups, legislated laws, enforcement agencies, and courts—whose interactions formalize standards of behavior for members of our society.

Reflecting the needs and desires of society, legislative groups at Federal, State, and local levels formulate and enact laws, including constitutions. Many of these constitutions not only establish enforcement agencies within the executive branch and courts within the judicial branch of government, but also give them authority to act on behalf of the American people. Aided by legislated laws and the courts, enforcement agencies try to maintain or produce law-abiding behavior in individuals or organizations[2] (legal system inputs and outputs) with respect to those actions regulated by law. The interactions between the legal system and its human inputs and outputs follow several sequential steps (fig. 1).

---

[1] *The information, courtesy of Albert J. Simard, is from an unpublished 1979 report, "Fire Statistics in the Northeast," on file at the U.S. Department of Agriculture, Forest Service; North Central Forest Experiment Station, East Lansing, MI.*

[2] *To avoid redundancy, the phrase "and organizations" will henceforth not be repeated each time with the term "individuals." ("Organizations" refers to corporations, groups, unions, business firms, institutions, etc.)*

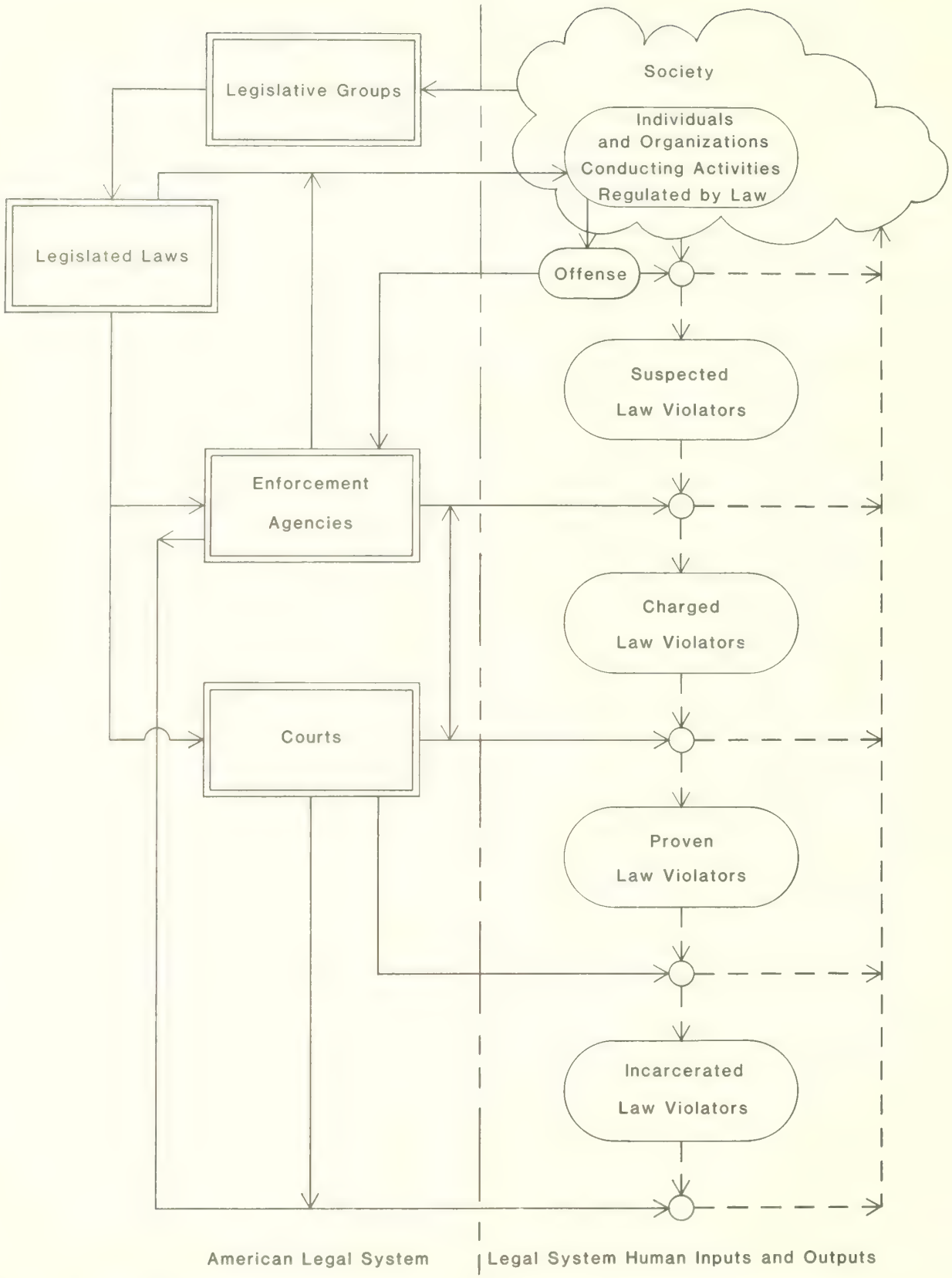

Figure 1.—*The American legal system and its interactions with people and organizations.*

Being aware of laws and the consequences of breaking them (e.g., knowing that burning without a permit is illegal and can result in a fine) provides enough incentive for most people to remain law-abiding. Individuals can, however, become *suspected law violators* if they are perceived to have done something wrong, whether or not they actually have broken a law. If the available evidence indicates that they have not broken the law, these individuals are no longer processed by the legal system for alleged offenses.

If, however, evidence seems to indicate a wrongdoing, *suspected law violators* become *charged law violators*; that is, they are formally charged in criminal cases or sued for a wrongdoing in civil cases. (To simplify terminology, we use the phrase *charged law violators* to cover both civil and criminal cases even though, technically, the term does not apply to civil cases.) People are no longer processed by the legal system if, during the trial, they are vindicated of illegal action.

If the courts, by assessing the facts and interpreting the law, find the *charged law violators* guilty, they become *proven law violators*. While the courts determine restitution or punishment for law violators, enforcement agencies generally ensure that the penalties are carried out. *Proven law violators* are considered law-abiding citizens when the courts and enforcement agencies agree that they've paid their fines, served their sentences (as *incarcerated law violators*), or otherwise made restitution for wrongful acts.

In the pages that follow, we define and describe in greater detail the four components of the American legal system and their interactions with one another and with individuals and organizations. We also discuss the relations and interactions of the Forest Service with each component.

LAW

Laws, as we are using the term in this paper, are standards of human conduct. They change, as society's needs and desires change, through custom and usage, judicial and religious interpretation, enactment, and other means (fig. 2). Laws that are currently accepted and followed by members of our society can be divided into two groups: (1) unlegislated laws, both written and unwritten, based on tradition and secular and religious principles, and (2) legislated laws (statutes, ordinances, and regulations), based in part on the former, that are established by groups such as Federal and State legislatures, city councils, and administrative agencies.[3] Although legislated laws are of primary importance to the legal system and to fire management specialists, two types of unlegislated laws—common law and equity—are invoked during enforcement and judicial proceedings when legislated laws do not exist.

Unlegislated Laws

Common Law: Common law is basically unwritten, judge-made law based on Anglo-Saxon customs and judicial precedent (Hemphill and Hemphill 1979). Its roots lie in the English legal system which had two types of courts existing side by side. The older of the two was known as the common law court. When ruling on cases, judges in these courts based their decisions primarily on previous court rulings that were considered high sources of authority and reflected customs of the day. Thus, the "doctrine of precedent," the essence of common law, was developed. Judges' decisions based on this doctrine (called *stare decisis* from the Latin, "let what is decided stand"), though authoritative, could be overturned on a showing of good cause.

Although most judicial decisions today are based on legislated law rather than common law, the importance of common law in our lives has not diminished, because most legislated laws can be traced to common law principles and rules.

Equity: In many cases common law courts in England either would not or could not act on behalf of individuals, or they made decisions that were too strict, narrow, and technical. Individuals could not file lawsuits, for example, unless the law addressed their particular circumstances. This frequently left complainants without any legal recourse in the courts. In addition, common law courts had no provisions, such as injunctions, for stopping or preventing a wrong against an individual. To correct these injustices, the English chancery or equity courts began to hear such cases. The net result of their activities was the creation of a set of rules and "principles to be applied when common law did not provide a suitable remedy for a particular wrong" (Kempin 1973). These rules and principles (called equity), existing alongside common law, thus provided an avenue for society to enlarge and adapt old rules to new views. Equity continues to be an integral and important part of American law.

---

[3] *Usually the term, "legislated law," refers to statutory laws passed by Congress or State legislatures (in contrast to court-made law). We are using the term in its broadest sense, i.e., making or giving laws (which, by our definition, include not only statutes but also ordinances and regulations) by an authorized Federal, State, or local legislative group.*

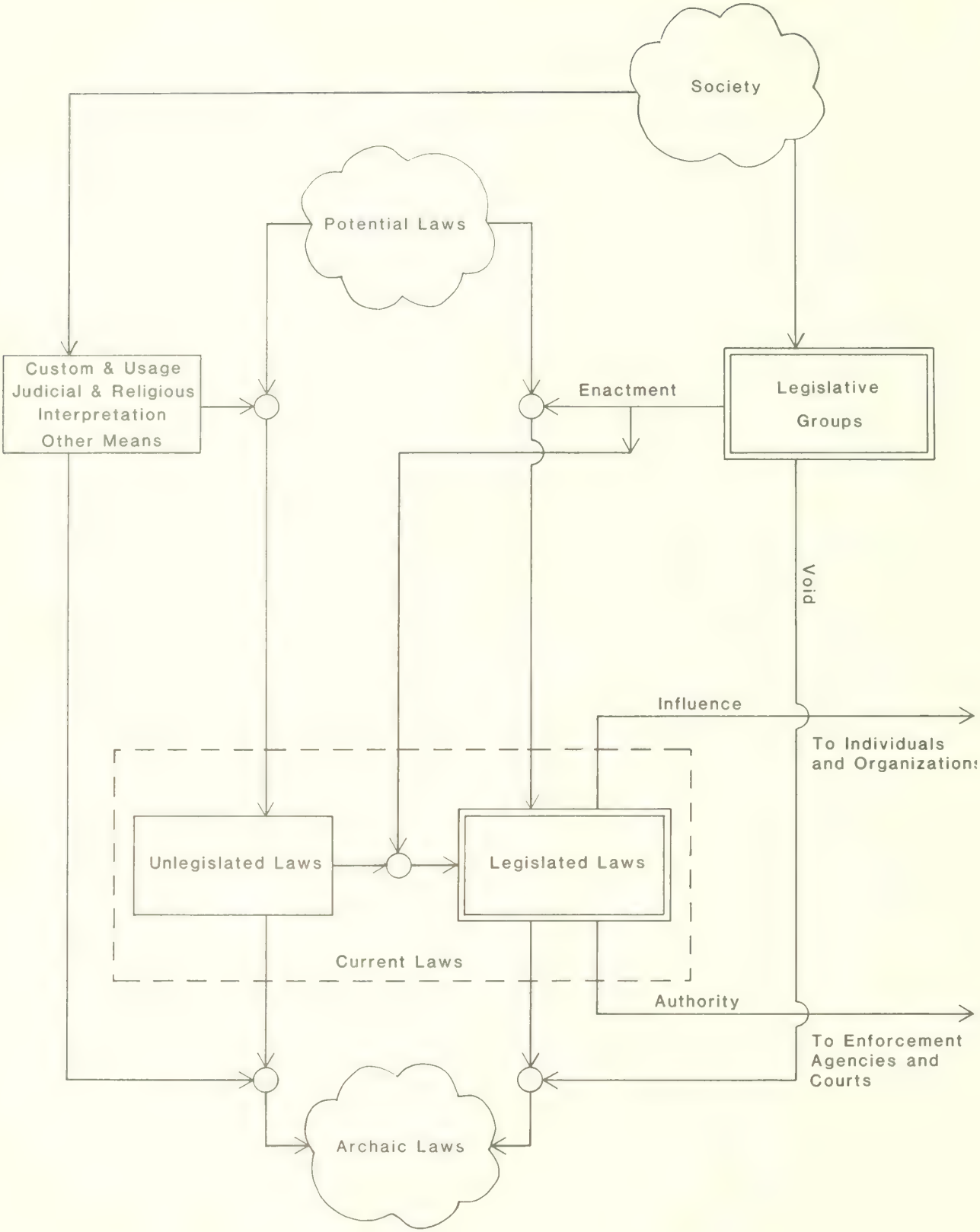

Figure 2.—*The law process.*

Legislated Laws

Common law and equity are not the only sources of law in America, however. After the Constitution was ratified in 1788, it became and continues to be the supreme law of the land. As the absolute rule of action and decision, the Constitution established the character and concept of our Government, including vesting legislative powers in a Congress. The Constitution thereby created a Federal legislative body with the power and authority to enact laws. Many State and local constitutions have since created similar legislative bodies. Although Federal, State, and local legislative groups have many nonlegislative powers, one of their most important functions is to make formal, written laws that prescribe conduct, define crimes, appropriate money, and, in general, promote the public good and welfare.

Written laws can be divided into three primary groups—statutes, ordinances, and regulations. Statutes are generally enacted by a legislative body such as the U.S. Congress or a State legislature; ordinances are enacted by lesser governmental groups such as city and village governments and county and township boards; and regulations are formulated by Federal, State, or local administrative agencies such as the U.S. Department of Agriculture.

Because increased governmental regulation has resulted in immense growth of statutory law in this country, Federal, State, and local governments have organized their laws into a number of codes for easier reference. Each code

> is a systematic compilation of both statutory law and the law handed down by the judges in their decisions. Typical examples of the state codes in use today are the probate, civil, penal, labor, political, administrative, educational, military and veteran's, health and safety, civil procedure, business and professions, and government code. Local governments also frequently adopt codes relating to firesafety, such as the electrical, building, plumbing, heating and ventilating, refrigeration, and fire codes (Bahme 1976).

The United States Code (USC) is particularly important; it arranges, under 50 titles, the statutes passed by Congress. (See Appendix I-A for an explanation of the USC, the United States Statutes at Large, and the United States Code Annotated.)

The Code of Federal Regulations (CFR) codifies (also under 50 titles) detailed regulations enacted by administrative agencies. (The authority to enact regulations is expressed in the legislation codified in the U.S. Code. See Appendix I-B and I-C for the definition and discussion of Forest Service regulations, orders, and notices and for procedures for formulating regulations.)

Although laws can be categorized by type such as statutes and regulations, they can also be categorized by subject matter such as corporate, tax, contract, property, civil, or criminal law. We are concerned with two major categories here—civil and criminal law—which are, to some extent, composites of legislated and unlegislated law.

Civil law, stemming from common law and equity, is the portion of law that defines and determines the personal and property rights of an individual. These include the right to personal safety, the right to privacy, the right to enjoy a good reputation (which is a protection against defamation of character), the right to personal liberty (which is a protection against unlawful arrest and false imprisonment), and the right to be secure in ownership of one's own property without unlawful interference from others (protection against trespassers, for instance).

While civil law defines and determines the personal and property rights of an individual, criminal law defines and determines acts that are contrary to the public good. A public wrong, or crime, is an injury to the order and peace of our entire society (whereas a civil wrong is an injury or violation of a personal or property right). This injury could come from "an act committed or omitted in violation of a law forbidding or commanding it" (Black 1979). Criminal law, which delineates offenses and their punishments, consists mainly of legislated law. Civil and criminal law and processes will be discussed in greater detail later in this publication.

Law in America—whether legislated or unlegislated; codified or uncodified; civil or criminal—is by no means static: Many of our laws are "subject to change through new decisions (some 30,000 a year) and new statutes (at least 10,000 a year) ..." (Cohen 1971). As a vital component of the American legal system, law enables people in our society, as individuals or as members of families, organizations, cities, or a nation, to function in a uniform manner resulting in the same general goals for all.

The Forest Service and Law

Although common law and equity are used in Forest Service legal activities, legislated laws are most important in both civil and criminal cases. For

decades Congress has enacted statutes—referred to as acts—pertaining to the Forest Service, its purposes, and its programs. For example, these statutes, covering a broad range of Forest Service activities, established the original Division of Forestry in the Department of Agriculture, created and stated the purpose of the National Forests, and in 1897 gave the Secretary of Agriculture the authority to make rules and regulations for the occupancy, use, and protection of the National Forests. Most of the principal laws affecting the Forest Service and its activities are found in the United States Code under Titles 7 (Agriculture), 16 (Conservation), 29 (Labor), and 43 (Public Lands).[4]

Congress passed two very important wildfire Acts, found under Title 18 (Crimes), that delineate criminal wildfire offenses and specify their punishments. The first Act, 18 USC Section 1855 *Timber Set Afire* states that anyone convicted of willfully starting fires on Governmental land could be fined not more than $5,000 or imprisoned not more than 5 years or could be sentenced to both a fine and imprisonment. The second Act, 18 USC Section 1856 *Fires Left Unattended and Unextinguished* states that anyone convicted of setting a fire on or near National Forest land and leaving the fire without extinguishing it or allowing it to burn beyond control could be fined not more than $500 or imprisoned not more than 6 months or could be sentenced to both a fine and imprisonment. (See Appendix II for the exact wording of these two laws.)

In addition to these Federal fire statutes, the Secretary of Agriculture has issued fire regulations (Subpart A—General Prohibitions—36 CFR 261.5) prohibiting the following activities in National Forests:

(a) Carelessly or negligently throwing or placing any ignited substance or other substance that may cause a fire.
(b) Firing any tracer bullet or incendiary ammunition.
(c) Causing timber, trees, slash, brush or grass to burn except as authorized by permit.
(d) Leaving a fire without completely extinguishing it.
(e) Allowing a fire to escape from control.
(f) Building, attending, maintaining, or using a campfire without removing all flammable material from around the campfire adequate to prevent its escape.

The maximum penalty for violating these regulations is $500 and/or 6 months imprisonment.

The preceding statutes and regulations apply to activities contrary to the public good (criminal wrongs). When an individual commits a criminal wrong (e.g., allows a debris fire to escape control), he or she may, at the same time, violate the property rights of the Forest Service (e.g., damage timber resources), thereby committing a civil wrong. Title 31 USC 951-953 (Federal Claims Collection Act of 1966) authorizes Federal agencies, such as the Forest Service, to sue for damages in civil court (Forest Service Manual [FSM] 6572.01).

No matter how many laws have been formulated to prescribe acceptable standards of human conduct, if they are not enforced regularly, they become meaningless. The next section, therefore, discusses law enforcement and enforcement agencies.

LAW ENFORCEMENT AND ENFORCEMENT AGENCIES

Although laws in our society prescribe conduct, define crimes, and in general promote the public good and welfare, they alone may not be enough to ensure law-abiding behavior in people. Enforcement is often necessary to make laws meaningful and effective. The term "enforce," according to *Webster's New Collegiate Dictionary* (1975), means to "strengthen; urge with energy; constrain or compel; carry out effectively." A number of Federal, State, and local laws give authority to and prescribe duties for law enforcement personnel; that is, they give law enforcers the right to influence or command desirable behavior. Thus, people with law enforcement responsibilities carry out the mandate or command of law, using a variety of measures, to encourage or, in some cases, force people to live by standards of conduct considered necessary to protect individuals and communities in our society.

Acting under the authority of law, enforcement people have as their primary goals to preserve peace, promote individual freedom, and protect life, property, and the constitutional rights of citizens. A number of methods are used to achieve these goals. They include public service, prevention, and repression.

Public service entails providing information, directions, and advice; serving summonses; and caring for the lost, sick, confused, distressed, or destitute, including delivering such people to a safe or helpful person or agency (counsel and referral).

Prevention involves juvenile and adult public education (instructing people about their duties, obligations, rights, and privileges under the law and helping

[4] *Consult the Forest Service Manual (FSM) 1021 (and following sections) for specific laws or the current Agriculture Handbook No. 453,* The Principal Laws Relating to Forest Service Activities.

them to identify factors detracting from their liberty and safety); education or rehabilitation of people in correctional facilities; preventive patrol and other visible evidence of police capability and availability; and probation and parole duties. Regulation is also an important component of prevention. Examples of regulation include licensing, inspecting, and/or controlling: traffic (vehicles, parking, pedestrians), public events (crowds), social relations (domestic disputes), and animal behavior.

Repression encompasses intelligence and surveillance work, detection and reporting of law violations, investigation, identification and apprehension of suspected law violators, arrest, presentation of evidence to prosecutors, participation in court proceedings, and detention.

The general relations between these law enforcement methods and activities and legal system human inputs and outputs are shown in figure 3.[5] While public service activities are directed toward society-at-large, prevention measures are targeted at society as well as suspected law violators (e.g., those given verbal or written warnings), incarcerated law violators, and those receiving out-of-jail or prison supervision. Repression activities are reserved primarily for people who enter the legal system for an alleged offense and are processed through the system as suspected, charged, proven, or incarcerated law violators. (A more detailed account of the relations between law enforcement personnel and people moving in and out of the legal system is given in the civil process and criminal process sections.)

As a group, law enforcement personnel employed by both public and private agencies perform an enormous variety of tasks that directly or indirectly aid law enforcement efforts in this country. Police, of course, are the most widely recognized law enforcement personnel; almost everyone has interacted with them at least once in his or her lifetime. Most of us commonly see State and local officers on preventive patrol, responding to emergencies, or ticketing people for traffic violations. But, in addition to patrol officers, other categories of police include park police; airport police; highway, bridge, and tunnel police; harbor and maritime police; transit and utility systems police; college and university police; and border patrols. Besides police, however, law enforcement personnel can also include:

- Parking enforcers
- Prosecutors and district attorneys
- Forensic medicine and crime laboratory employees
- Private security forces
- Probation, parole, and correctional institution employees
- Fire marshals
- Fish and game wardens
- Inspectors (e.g., postal, food and drug)
- Management and administrative employees in law enforcement agencies.

Regardless of the job or duties performed, law enforcement personnel can be divided into civilian or sworn employees. We define civilian employees as individuals who have not taken an oath of office and who are not authorized to make arrests (e.g., district attorneys, forensic scientists, legal advisors).[6] In contrast to civilian employees, sworn employees (most often a public police officer) are persons who have taken an oath of office (received formal authority) and possess the general power of arrest.[7]

Enforcement personnel can also be divided into generalists or specialists. A generalist is an individual with a wide range of public service, prevention, and repression duties and responsibilities (e.g., village, city, or township patrol officers, county sheriffs, and

[5] *Figure 3 does not list all law enforcement activities, but rather illustrates major activities that can occur as people move through the legal system. The nature of an offense (whether civil or criminal) and the stage of the law violator in the civil or criminal process determine the types of repressive activities brought into play. Interactions between law enforcement personnel, grand juries, and juveniles are not shown.*

[6] *According to Germann* et al. *(1977), an arrest is*

> *the taking of a person into custody for the purpose of charging him with a crime.... Technically, in most jurisdictions, anyone, citizen or officer, can make an arrest for a misdemeanor or felony offense attempted or committed in his presence, for a felony offense committed, even though not in his presence, and on charges made by another that a felony offense has been committed.... For the most part, the business of arrest is left to the law enforcement officer who is presumed to have the training and judgment necessary to make a good arrest.*

[7] *Gottfredson* et al., *eds. (1978), define the general power of arrest as*

> *the power to suppress with force all breaches of the peace, riots, tumult and unlawful assemblies, power to serve all criminal process, including the power to arrest a person without a warrant if the person is apprehended in the process of committing an unlawful act or if he or she obtains "speedy information" by other persons.*

Thus, a sworn law enforcement employee has much broader powers of arrest than a private citizen.

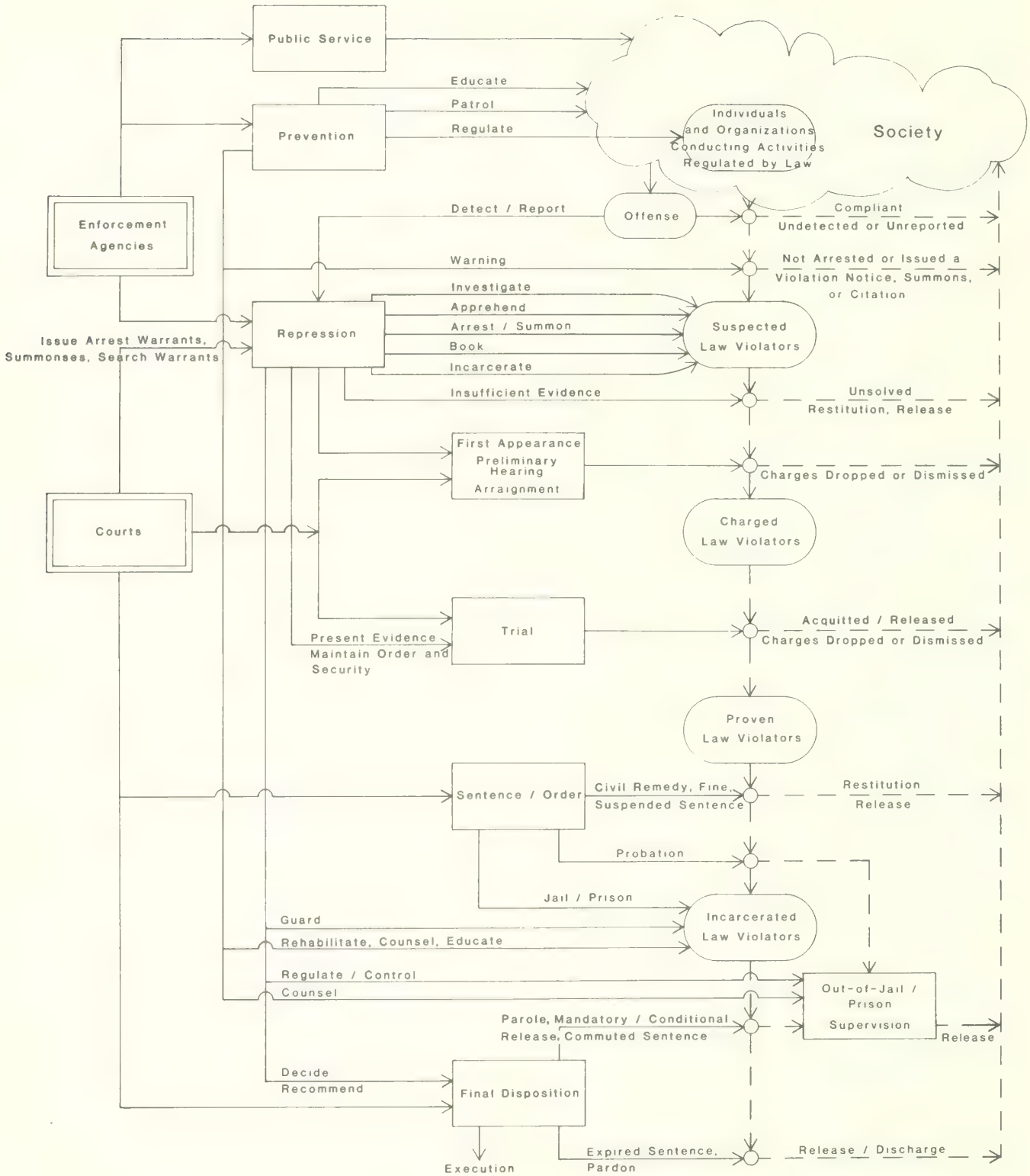

Figure 3.—*The relations among the law enforcement component (Enforcement Agencies) and subcomponents (Public Service, Prevention, Repression) of the American legal system and the system's human inputs and outputs.*

some State troopers); a specialist is a person concentrating his or her activities in limited areas such as narcotics, vice, organized crime, traffic safety, jail, criminal investigations, or civil wrongs.

Law Enforcement Agencies

There is no central law enforcement agency in the United States. Instead, law enforcement is the responsibility of a number of agencies on all three levels of government—Federal, State, and local. On the Federal level, for example,

> Thousands of people work in some twenty major, and scores of minor, law enforcement or investigatory units of federal government. These units are located in the Executive Office of the President, in the major federal departments, in the independent agencies, and in various minor boards, committees, and commissions .... Some deal primarily with security matters, others with criminal matters, others with regulatory matters of a quasi-criminal-civil nature, and others with military matters (Germann *et al.* 1977).

Although these units exercise wide territorial authority, their duties range from very strong enforcement to relatively minor inspections and investigations.[8]

Although both State and local agencies also vary enormously in character and law enforcement responsibility, agencies at all three levels of government can be grouped into the following general categories:

Government Attorneys. Examples: Attorney General of the U.S., State Attorney Generals, county prosecuting attorneys, city attorneys. As public representatives and chief law enforcement officers of their respective governments, public attorneys represent their governments in criminal and civil legal matters. They also advise their chief executives (e.g., the President, governor, mayor) and heads of governmental departments, respond to consumer complaints and needs, intervene in court cases to protect the rights of citizens, and/or charge and prosecute law violators in courts of law.

Police. Examples: U.S. Marshals Service, State police, county sheriffs and constables, city police. Their duties can cover the whole spectrum of law enforcement as we have defined it—from public service to repression. Michigan sheriffs, for example, supply patrol services in a county, investigate crimes, oversee jail facilities, provide rehabilitation and vocational training for inmates, and maintain a lake and river boat patrol in some of their jurisdictions. Sheriffs in other States can be responsible for everything from assessing property and collecting taxes to determining the causes of unusual deaths in a county and carrying out a death penalty imposed by a court.

Corrections. Examples: U.S. Bureau of Prisons and Parole Commission, State Departments of Corrections, county detention centers. Correctional agencies are responsible for the custody and care of incarcerated law violators and for their supervision after they leave jail or prison. These agencies not only run the nation's prisons, jails, halfway houses, reformatories, and related institutions, but also, on a Federal and State level, grant, deny, or revoke parole for imprisoned offenders. (For a discussion of imprisonment, see Appendix III.)

In addition to these agencies, investigatory and enforcement units of other Federal, State, and local departments (e.g., agriculture and natural resources, military, public health and safety, finance, commerce, employment, insurance, investment, civil service, industrial relations, marketing) also conduct a wide variety of civil and criminal enforcement functions.

Forest Service Law Enforcement

Realizing that Congressional statutes and Forest Service regulations may not be enough to ensure law-abiding behavior in people using National Forest lands, Congress gave the Forest Service authority to make these statutes and regulations both meaningful and effective—through law enforcement. The acts giving the Forest Service law enforcement authority and prescribing its enforcement duties include the following:[9]

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[8] *A detailed account of Federal agencies that have law enforcement duties can be found in* The United States Government Manual, *published by the General Services Administration (GSA). For the most recent copy of the* Manual, *write to: Office of the Federal Register, National Archives and Records Service, Washington, DC 20408. Because the structures, jurisdiction, and responsibilities of State and local law enforcement agencies differ from State to State and department to department, we suggest that readers wishing to familiarize themselves with their own State and local structures contact their Governor's office, State police, county board of commissioners, or local police for more information.*

[9] *For a more complete discussion of these acts, see FSM 5301. For exact wording, consult the current Agriculture Handbook No. 453,* The Principal Laws Relating to Forest Service Activities.

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- Title 16 USC 551, 480, *Organic Administration Act*, authorizes the Secretary of Agriculture to regulate the occupancy and use of National Forests and to preserve these forests from destruction; specifies the penalty for violating the Secretary's rules and regulations (a fine of $500 or imprisonment for 6 months, or both); and, except in cases of Federal law violations, allows States to retain civil and criminal jurisdiction over persons on National Forest land.
- Title 16 USC 559, *Authority to Arrest*, authorizes Forest Service employees (Forest Officers) to arrest violators of Federal statutes and regulations pertaining to the National Forests and to take them before the nearest U.S. Magistrate (having jurisdiction) for trial.
- Title 16 USC 553, *Aid to States and Federal Agencies*, permits authorized, and sometimes deputized, Forest Officers to help enforce State livestock, fire, fish, and game laws when this aid furthers the interests of the Forest Service. Under this Act, the Forest Service is also authorized to aid, when requested, other Federal bureaus and departments performing law enforcement duties on National Forests.
- Title 16 USC 551a, *Cooperation by the Secretary of Agriculture with States and Political Subdivisions in Law Enforcement*, authorizes the Secretary of Agriculture to help State or local governments enforce State and local laws on lands within the National Forest System.
- Title 7 USC 2217-2218, *Authority for Taking Oaths and Affidavits*, authorizes designated Forest Officers to administer oaths and affidavits in order to enforce statutes and regulations pertaining to lands under Forest Service control.

Acting under the authority of these laws, Forest Service enforcement personnel have as their primary objective to develop and maintain a law enforcement program that will help ensure (1) compliance with statutes and regulations, (2) protection of the public and their property, (3) protection of Forest Service employees, (4) protection of forest resources and property, and (5) protection of the public's rights and interests in the National Forest System.

Prevention and repression, summarized in figure 3, are the primary methods used to achieve these goals. Prevention methods include: informing National Forest users of applicable statutes and regulations, patrolling forest areas to deter law violations, and tactfully advising people of potential law violations. Prevention regulation activities include issuing burning permits to residents for debris disposal and closing forests to public use during high fire-danger.

Repression activities in the Forest Service are limited primarily to suspected and charged law violators (fig. 3). These activities include writing violation notices; investigating reported or observed law violations; detecting the elements of crimes; collecting evidence (and recovering stolen property) to present to prosecutors; apprehending suspected law violators; arresting them for an appearance before a U.S. Magistrate or U.S. District Court judge; and presenting evidence against suspected and charged law violators in court.

Law Enforcement Personnel

Although all Forest Service employees are obliged to observe and report offenses and are authorized to arrest, the primary law enforcement personnel in the agency are Special Agents, Law Enforcement Officers, and Forest Officers trained to do relatively routine enforcement work. With few exceptions, Special Agents are the only full-time law enforcement employees in the Forest Service. As graduates of Federal law enforcement academies, they are highly trained specialists in criminal investigation. In addition to their important investigative duties, they direct both the cooperative and the in-service law enforcement programs,[10] and conduct law enforcement training courses for Forest Officers. They also advise Law Enforcement Officers and aid the latter in special situations requiring an agent's expertise and experience, e.g., situations involving confrontations between Forest Service employees and large groups of potentially violent people. Special Agents, like city detectives, wear plain clothes and travel in unmarked cars, carry firearms and credentials, and have the power to arrest and to perform search-and-seizure activities. They are assigned either to a National Forest with a heavy and complex investigative workload or to a large geographic area with more than one forest if the workload on one forest is not sufficient to require a full-time Special Agent.

[10] *In directing the Cooperative Law Enforcement Program designed to protect forest-using people and their property, Special Agents serve as liaisons between the Forest Service and other law enforcement agencies. As directors of the in-service programs, designed to protect forest resources, Governmental property, and Forest Service employees, Special Agents provide technical advice and information to line and staff members involved in law enforcement situations or problems.*

Regional Special Agents (one per Region) spend most of their time in the office, directing Regional Law Enforcement Programs, coordinating law enforcement activities, supplying technical advice, and performing other administrative tasks. Occasionally, they travel to various National Forests to assist with special criminal investigative or other law enforcement problems.

In contrast to Special Agents, Forest Service Law Enforcement Officers are much like "patrol" officers. They wear uniforms, patrol in marked vehicles, and carry credentials, but are not authorized to carry firearms unless they're exposed to significant and continuing elements of risk. Most Law Enforcement Officers are assigned to forests or districts with unusually heavy and complex enforcement workloads and spend 10 to 50 percent of their time in law enforcement activities. In order to function in a professional manner, these employees receive at least 9 weeks of full-range law enforcement training (designated Level IV training) at the Federal Law Enforcement Training Center, Glynco, Georgia, or at State law enforcement academies.

Although all Forest Service employees are considered Forest Officers, we use the term here to refer to employees receiving a minimum of 1 week (Level II) or 3 weeks (Level III) of law enforcement training. Their routine enforcement duties (averaging 5 to 20 percent of their time) include patrolling, preliminary investigative work, and issuing violation notices for petty offenses such as littering, improper campfire construction, or nonpayment of fees. They may also advise Forest Supervisors and District Rangers on enforcement and investigative problems and assist Special Agents in investigations. Although Level II and III Forest Officers are not allowed to carry firearms (Level III's can carry mace), they do have authority to arrest; this activity, however, is normally relegated to Special Agents and Law Enforcement Officers.

Law Enforcement Agencies

Forest Service law enforcement personnel interact with the following law enforcement departments, bureaus, agencies, and personnel on Federal, State, and local levels:

Office of the General Counsel (OGC). Attorneys from the OGC, the principal legal advisor in the USDA, are stationed in various field locations as well as in their Washington, DC, headquarters. Among other duties, they provide legal advice to the Forest Service, draft or review proposed legislation, prepare and interpret a wide variety of legal documents such as contracts, resolve legal disputes outside of court, and prepare Forest Service cases for U.S. Attorneys.

Office of the Inspector General (OIG). The OIG has authority to conduct investigations into all programs and administrative activities of the USDA. Areas of investigative jurisdiction between the Forest Service and the OIG are clarified in a statement of determination between the two agencies. (See FSM 5350.43b.)

Federal Bureau of Investigation (FBI). Law enforcement personnel from each National Forest and the nearest FBI special agent-in-charge establish informal agreements to outline which Federal law violations will be reported to the FBI. (The FBI has jurisdiction to investigate violations of Federal statutes but not violations of Forest Service regulations.) For instance, the FBI may investigate law violations for the Forest Service if the amount involved is more than $5,000, or, in the case of assault, if someone is injured. Because of their special expertise in natural resources, however, Forest Service law enforcement personnel generally conduct their own investigations.

The National Crime Information Center (NCIC) in the FBI headquarters, Washington, DC, is used by the Forest Service to investigate a suspect's criminal history or to report stolen Governmental property bearing serial numbers.

U.S. Attorneys. Each U.S. Attorney under the Attorney General in the Department of Justice supports Forest Service law enforcement efforts within his or her own judicial district (the U.S. is divided into 95 judicial districts). This support includes: (1) prosecuting Federal felony and misdemeanor violations in U.S. District Courts and U.S. Magistrates' Courts, (2) preparing and/or acquiring Federal complaints, written accusations, warrants, and injunctions, and (3) initiating lawsuits to recover damages resulting from violations of Forest Service statutes and regulations.

U.S. Marshals Service. The U.S. Marshals Service, also within the Department of Justice, performs a wide range of law enforcement tasks in the 95 U.S. districts. Although the marshals' duties include attending court and preserving order in the courtroom, protecting Governmental witnesses, and quelling civil disturbances, the Forest Service uses the marshals primarily to serve arrest warrants or summonses and to transport suspected law violators to the proper authorities.

State and Local Agencies. Because of overlapping State and Federal jurisdiction, Forest Service law enforcement personnel cooperate with State and local law enforcement units such as State forestry and wildlife agencies, State police, county sheriffs, and/or county, city, or township police. Forest Service employees may, for example, provide local law enforcement officials with observed evidence. When an

offense occurs on National Forest land that is a violation of both Federal and State laws, a State or local law enforcement agency may investigate the incident and apprehend the suspect. In such cases, most U.S. Attorneys prefer that the suspected law violator be prosecuted by the State.

Even though law enforcement agencies conduct a wide range of public service, prevention, and repression activities, often with the aid of cooperating agencies, they must rely on Federal and State courts to administer justice. The next section describes Federal and State court systems and discusses their structure and jurisdiction.

COURTS

Courts, the fourth component of the legal system, are also used by our society to maintain order. The term "court" is used here to mean an organized body of individuals (one or more judges and often a jury) "with defined powers, meeting at certain times and places," primarily to hear and decide cases and other matters brought before it (Black 1979). The court is aided by officers such as attorneys or legal counselors who present and manage business, clerks who record and attest to the court's acts and decisions, and bailiffs who execute the court's demands and secure order in the courtroom (Black 1979). (The words "court" and "judge(s)" are frequently used synonymously.)

Courts and law are interdependent: On one hand, laws establish the courts and limit their power, while on the other, courts can, in some sense, make law. The Constitution (Article III, Section I), for example,

> generates the authority for the establishment of courts in the federal system. The Supreme Court is the only federal court mandated by the Constitution. All other federal courts are established by acts of Congress. . . . State court systems are also created under the auspices of their respective state constitutions (Chamelin *et al.* 1975).

In addition, laws establish court jurisdiction (authority of a court to handle a case—see Appendix IV), limit the sentences judges can impose, and, in the case of a constitutional amendment, override court decisions.

Guided by common law principles, court decisions can, however, have the effect of law.

> Notwithstanding the separation of powers concept and the belief that courts do not make laws, it is somewhat unrealistic and academic to believe that lawmaking does not occur whenever the court renders a decision. Every constitutional interpretation, every declaration of statutory constitutionality or unconstitutionality makes law in the broadest sense of the word. It is true that courts do not enact laws in the same manner as legislatures and the Congress, but the impact of court decisions does set standards of social and legal policy (Chamelin *et al.* 1975).

Like the courts and the law, courts and law enforcement agencies are also inextricably bound together. For example, law enforcement personnel, in many cases, control the flow of people going before the courts. They also serve summonses issued by the courts; present evidence to judges during initial appearances, preliminary hearings, and trials; serve as witnesses in court proceedings; maintain order and security in courtrooms; ensure that restitution is made or that sentences are carried out after trials; and, in conjunction with the courts, decide on final dispositions of incarcerated law violators (fig. 3). Without law enforcement personnel, the courts' role in society would be severely curtailed.

The courts' primary purpose is to administer justice, that is, to settle disputes, interpret and apply the law, provide checks and balances restraining the executive and legislative branches of government, and administer judicial proceedings (Ferguson and McHenry 1959). This involves, but is not limited to:

- Fact finding
- Interpreting the meaning of obscure words and phrases in law(s) applied to concrete situations
- Conducting trials and civil and criminal procedures (e.g., issuing summonses or warrants, setting bail, appointing grand or petit juries, admitting attorneys to practice, assessing and collecting fees, admitting evidence, implementing penalties enacted by legislatures)
- Examining, selecting, and appointing clerks, commissioners, messengers, stenographers, and other assistants
- Handling noncontentious cases, i.e., those in which parties are not in dispute (e.g., administering estates, appointing receivers in bankruptcy, issuing licenses, performing marriages, naturalizing aliens).

Structure and Jurisdiction of Federal and State Court Systems

A dual system of courts exists in this country—a Federal system and a State system.

> The two systems are sovereign and often foreign to each other. Although the structure of the federal court system is uncomplicated and precise, no such simple universality exists in state court systems. Few states have identical courts with identical patterns of jurisdiction. Even within a state, it is often difficult to detect similarities between courts of the same title from county to county, or from judicial circuit to judicial circuit (Chamelin *et al.* 1975).

Federal Courts

The Federal court system is basically three-tiered. The Supreme Court is at the apex, the 12 U.S. Courts of Appeals at the intermediate level, and the 95 U.S. District Courts and Territorial Courts at the bottom of the pyramid. A number of other specialized courts are also in the Federal system (Chamelin *et al.* 1975) (fig. 4).

The Supreme Court of the United States is the highest tribunal (and generally the court of last resort) in our dual system of courts (State and Federal). Its role is "not to right every wrong in the lower courts, but to resolve major issues in the law and to set policies for the rest of the system. The Court chooses its cases accordingly" (Berkley *et al.* 1976). (Unlike most other courts, the Supreme Court can decide which cases it will hear.) The nine justices constituting the Court hear cases from a variety of sources. Although the Supreme Court has original jurisdiction in some cases, most of its work involves settling appeals from the U.S. Courts of Appeals and from State courts of last resort, if a Federal question is at issue. It also hears a lesser number of cases from special Federal courts or on direct appeal from U.S. District Courts (Berkley *et al.* 1976).

Each of the 12 *U.S. Courts of Appeals* (on the second level of the Federal court system) reviews orders issued by administrative and regulatory agencies for errors of law and hears both civil and criminal Federal cases on routine appeal from U.S. District Courts within its geographic area (circuit). (The States and U.S. territories are divided into 11 circuits. The District of Columbia constitutes the 12th circuit.) These cases, involving difficult and complex legal questions, are decided by a three-judge panel.

The 90 *U.S. District* and five *Territorial Courts*, the main Federal trial courts, are on the third level of the Federal system. (Each State has at least one U.S. District Court.) Usually one judge presides over each of these courts. With or without a jury, the judge hears and decides civil cases (dealing with bankruptcy, fraud, patents, and many other violations of Federal laws) and criminal cases (dealing with Federal crimes such as treason, kidnapping, or incendiarism). *U.S. Magistrates* appointed by U.S. District Court judges have some, but not all, of the powers of the judges.

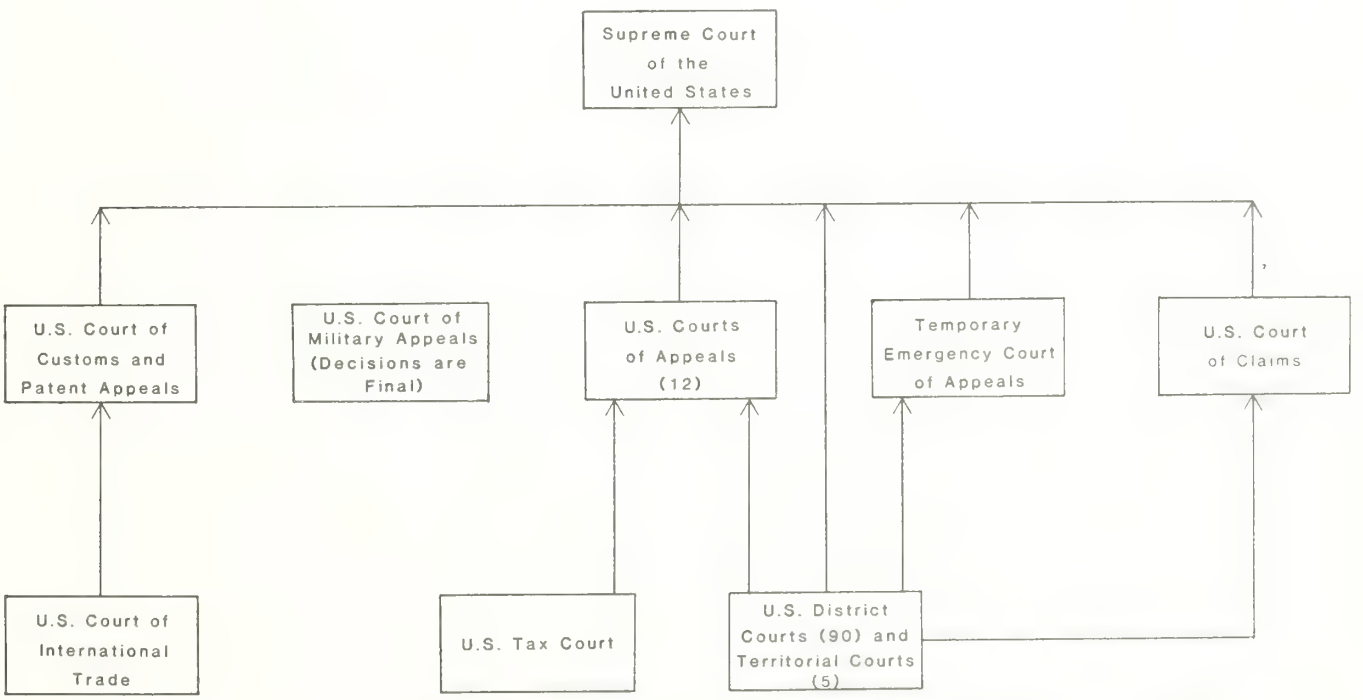
Supreme Court of the United States
U.S. Court of Customs and Patent Appeals
U.S. Court of Military Appeals (Decisions are Final)
U.S. Courts of Appeals (12)
Temporary Emergency Court of Appeals
U.S. Court of Claims
U.S. Court of International Trade
U.S. Tax Court
U.S. District Courts (90) and Territorial Courts (5)

Figure 4.—*The United States Federal court structure. A more detailed explanation of these courts and their relations to one another can be found in* The United States Government Manual.

They conduct many of the preliminary or pretrial proceedings (e.g., issue warrants, fix bail, hold preliminary hearings) and try, without a jury, misdemeanors—those punishable by imprisonment for 1 year or less or by a fine of $1,000 or less, or both. In addition to U.S. Magistrates (and other court personnel), the U.S. District Courts are also assisted by U.S. Marshals, who supervise "federal prisoners and serve court writs and orders," and U.S. Attorneys, who "prosecute federal cases and represent the United States in civil cases" (Berkley *et al.* 1976). Each Federal District Court has one U.S. Marshal and one U.S. Attorney.

A number of special trial and appellate Federal courts with limited jurisdiction were created by Congress to deal with particular types of cases. These courts include the U.S. Court of Customs and Patent Appeals, U.S. Court of Military Appeals, Temporary Emergency Court of Appeals, U.S. Court of Claims, U.S. Court of International Trade, and U.S. Tax Court.

State Courts

> As noted earlier, it is an impossible task to attempt a uniform explanation of state and local systems. The variances in functions, jurisdiction, and even titles are so great that no simple statement can have universal acceptance .... The court system in a particular state may consist of two, three, four, or more levels of courts. Where the levels are fewer, the functions and jurisdictions of each level may be broader (Chamelin *et al.* 1975).

As in the Federal Government, a State *Supreme Court* (also known as the Court of Appeals, Supreme Court of Appeals, Supreme Judicial Court, Supreme Court of Errors, or Court of Criminal Appeals) is the highest State judicial tribunal and hears selected appeals from intermediate courts of appeal and/or from major trial courts. State Supreme Courts are "the ultimate and final interpreter of state constitution and laws unless federal law or some aspect of federal law is involved" (Rosenbauer 1978).

Intermediate appellate courts (called Superior Courts, District Courts of Appeals, Appellate Courts, or Supreme Courts in some States) form the second level of courts in less than half of the States. States that are divided into districts have more than one court at this level, although most of the courts have statewide jurisdiction. State appellate courts hear both civil and criminal cases on appeal from lower trial courts, and many of their decisions based on these cases stand as law.

Major trial courts (known as Circuit Courts, District Courts, Superior Courts, or State Courts) usually serve a "district or circuit comprised of several counties, but in a few States a major trial court may be located in each county" (Berkley *et al.* 1976). They not only have original jurisdiction in serious or important civil and criminal cases, but they also review decisions of State administrative agencies and "handle appeals from ... minor courts although these cases are generally heard as completely new trials" (Rosenbauer 1978).

Minor trial courts, of limited and special jurisdiction in both rural and urban areas, serve as the primary entry point for those who become involved in the judicial process.

> For those millions of Americans who ... [go before the courts] for minor offenses, including traffic violations, these lower courts serve as the only contact with the judiciary. Ninety percent of all criminal cases are heard in these lower courts. Historically, the lower courts are most important to the ... [legal] system because of the sheer number of cases handled. They are also the portion of the American judicial system most visible to the public (Chamelin *et al.* 1975).

The Forest Service and the Courts

Violations of Federal statutes and Forest Service regulations are prosecuted in Federal District Courts, whereas State, county, or city courts handle violations of State laws and county or city ordinances. Either State or Federal courts (or both) may hear cases involving violations of Federal and State criminal laws covering the same offense. Civil cases are taken either to U.S. District Courts or to the U.S. Court of Claims, depending on the damages sought.

When the Forest Service takes civil or criminal cases to court, the cases are generally tried before U.S. Magistrates or U.S. District Court judges. (There are 17 U.S. District Courts in Region 9 alone.) In addition to hearing Federal civil cases, the U.S. Magistrates try and sentence persons charged with violating regulations contained in 36 CFR 261 (protection, occupancy, and use of National Forest land).[11]

[11] *Not everyone cited for violating a Forest Service regulation must appear before a U.S. Magistrate. This depends not only on the discretion of the Forest Officer issuing the violation notice, but also on the local rules of the Federal District Courts, which maintain lists of petty offense misdemeanors that can be remedied by*

Violations of these regulations are petty offense (low) misdemeanors. In some judicial districts, however, the U.S. Magistrates may be authorized to try and sentence persons charged with more serious (high) misdemeanors, usually handled by the District Court judge.

U.S. District Court judges, on the other hand, try cases beyond the jurisdiction of the U.S. Magistrates, e.g., they usually hear more serious civil cases, criminal cases such as Federal felonies and high misdemeanors, and cases in which a person accused of committing a petty offense misdemeanor refuses to be tried before a U.S. Magistrate. District Court judges may also issue injunctions. Both the U.S. Magistrates and District Court judges issue search and arrest warrants, subpoenas, and summonses to Forest Service law enforcement personnel authorized to administer them.

Violators of State and Federal laws covering the same incident are prosecuted in State courts when the U.S. Attorney declines prosecution in favor of the State. The U.S. Attorney may decline to prosecute a case due to a heavy case load and give permission to the Forest Service to prosecute in State court. U.S. Attorneys normally prefer State prosecution of cases when State or local law enforcement agencies have conducted the investigation and apprehended the violator. Juveniles suspected of violating Federal laws and regulations can be prosecuted in Federal courts only after U.S. Attorneys have received authorization from the Attorney General to initiate such an action.

Up to this point, we've described the four components of the American legal system—legislative groups, legislated laws, enforcement agencies, and courts—and their relations to one another and to the Forest Service (left side of fig. 1). What remains is how individuals (suspected, charged, proven, and incarcerated law violators) enter, move through, and leave the legal system—that is, how the system processes its human inputs and outputs (right side of fig. 1). The following two sections, civil process and criminal process, describe in greater detail the routes people take through the legal system.

paying fines and petty offense misdemeanors that require a court appearance. Most offenders post collateral in the amount set by the court, waive appearance before the court, and consent to forfeiture of the collateral.

CIVIL PROCESS

Basically, the civil process is the procedure through which a person[12] with a claim against another can institute an action (lawsuit) in court and seek a remedy for a violation of his or her personal or property rights.[13] Its purpose, therefore, is to rectify a noncriminal wrong by compensating the person wronged.

Noncriminal or civil wrongs can be divided into two major types—breaches of contract and torts. A contract is a definite agreement, written or oral, between two or more competent persons that creates a legal obligation and is enforceable in the courts. If one party to a contract fails to do what he or she had agreed to do, he or she has breached the contract and the other person usually is entitled to some form of remedy. A tort, on the other hand, is an injury that one person, either intentionally or negligently, does to the body, property, or reputation of another (Dolan 1972). It's an invasion of any private or personal right which each of us has by virtue of the law and a wrong for which the law provides relief. According to Dolan (1972),

> The principal torts are: *false arrest, false imprisonment,* and *malicious prosecution,* each of which violates the right to personal liberty; *defamation (slander* and *libel),* which violates the right to a good reputation; *assault* and *battery,* which violate the right to personal safety; and *negligence,* which violates not only the right to personal safety but also the right to be secure in the ownership of property.

Other torts violating the right to be secure in property ownership are trespass and conversion (taking someone else's property for one's own use). "Personal rights are most frequently violated by someone's negligent behavior. In any year negligence accounts for thousands of lawsuits and takes up more court time than any other kind of action" (Dolan 1972).[14]

[12] *Parties to a lawsuit or civil action (plaintiffs and defendants) can include not only individual citizens but also groups of citizens, partnerships, companies, corporations, and Federal, State, or local governments. To simplify our discussion of the civil process, we will assume that parties to a lawsuit are two individuals.*

[13] *Guaranteed under the law and protected by law, personal rights granted to people in our society include (1) the right to personal liberty, (2) the right to personal safety, (3) the right to be secure in ownership of property, and (4) the right to enjoy a good reputation. A violation of any one of these rights constitutes a civil wrong (Dolan 1972).*

A number of judicial remedies are available to people whose personal or property rights have been violated, but the most well known of these are money damages, injunctions, and specific performance of contracts. Money damages, the most common remedy for civil wrongs, are available to plaintiffs in nearly all types of civil complaints, whether based on breaches of contract or on torts. In most cases, however, money damages are not a specific form of relief, i.e., plaintiffs are not given precisely what they are entitled to under the law but are paid money damages instead. In lawsuits for breaches of contract, plaintiffs seek damages that will place them in positions they would have been in had the defendants fulfilled their part of the contracts. In tort actions, on the other hand, the object of money damage awards is to place the plaintiffs in positions they would have been in had the defendants not violated their rights.

Money damages can be classified in three ways:

- **Nominal** damages are awarded to plaintiffs when the injuries suffered are considered slight. The plaintiffs may receive a trifling amount to remedy violations of their rights and to compel defendants to pay for court costs.
- **Punitive** damages are awarded to plaintiffs over and above those actually suffered as a means of punishing defendants for their malicious or vicious conduct.
- **Compensatory** damages, awarded in most civil cases, compensate plaintiffs for losses suffered. These damages include not only all out-of-pocket losses (e.g., repair, restoration, or replacement costs of damaged property; lost wages; medical bills), but also general compensation for pain, suffering, injury, humiliation, and emotional upset caused by the defendant's misconduct.

[14] *Negligence is at issue in many Forest Service tort claims. According to Chandler* et al. *(1983),*

> *In law, negligence is the opposite of diligence and signifies the absence of care. It implies a failure of duty, but excludes the idea of intentional wrong. Negligence is not absolute or intrinsic, but always relative to some circumstance of time, place or person. The test of negligence is what should be expected of a reasonable person acting with proper regard for others under the same circumstance. If [for example] a property owner allows his land to become in such a condition as to constitute a danger to other property in case of an accidental fire, he may be considered negligent.... If a fire loss results from willfulness or intent rather than carelessness, then the concept of negligence does not apply.*

Injunctions, specific performance of contracts, and similar remedies for civil wrongs differ in several respects from damage remedies. First, they are regarded as extraordinary remedies, granted only if plaintiffs prove that money damages are inadequate. Second, they are specific in that the plaintiffs—in lieu of money—are given the very thing to which they are entitled. Third, injunctions and similar equitable remedies look to the future rather than to the past; the defendants are ordered either to do or not to do certain actions in the future. (The damage remedy looks to the past—to compensate plaintiffs for what defendants have done to cause the plaintiffs damage or injury.)

Generally, an injunction, the most common form of "specific" remedy, is a court command or order to a defendant *to refrain* from particular acts that he or she is doing or threatening to do. Specific performance, on the other hand, is a court order requiring the defendant *to do* the act he or she had promised to do in a contract.

The process through which a person with a claim[15] against another can institute a lawsuit in a court and seek a remedy for a civil wrong is described in detail in Appendix V.

The Forest Service and the Civil Process

Because the Forest Service annually experiences hundreds of violations of its rights resulting in millions of dollars in losses,[16] it often needs to rectify these wrongs through the civil process.

The Forest Service regularly faces both breaches of contract and torts. A typical timber breach of contract occurs when the Forest Service sells timber to a contractor who doesn't finish harvesting the stand. By far the most usual tort is property trespass, including both timber and fire trespass. The former can occur when a person buys and harvests trees from a private landowner but also accidentally or intentionally cuts down trees belonging to the Government and the latter when a fire on private land burns out of control onto National Forest land.

[15] Webster's New World Dictionary *(1968) defines a claim as "a demand for something rightfully or allegedly due; assertion of one's right to something."*

[16] *At least twice as many claims are filed against the Forest Service (causing the Service to be the defendant) as the Service files against individuals and organizations (when the Forest Service is the plaintiff). This publication, however, is primarily concerned with those claims that the Service (as the plaintiff) files to defray losses to the U.S. Government.*

When it has experienced a breach of contract or a tort, the Forest Service has the same judicial remedies available as a private citizen, e.g., money damages, injunctions, and specific performance of contracts; but damages are the most common form of remedy sought. Because the Service does not have statutory authority to initiate lawsuits, its legal proceedings, except for cases taken to Small Claims Court, are generally handled by the OGC and U.S. Attorneys.

In fire trespass cases, for example, a U.S. Attorney may file claims on behalf of the Forest Service against the trespassers, not only for resources damaged or destroyed by fire, but also for fire suppression costs, which are generally 10 times greater than resource damages.[17] Potentially, all of the 6,615 human-caused fires occurring on National Forest lands in 1980 were fire trespass cases (USDA Forest Service 1975-1980); however, trespassers cannot always be identified and, therefore, required to pay for their civil wrongs. As a result the Forest Service attempts to collect damages each year for approximately one-sixth of the human-caused fires occurring on the National Forests.[18]

All Forest Service employees are responsible for notifying their supervisors of incidents that may result in claims for the Government. Following such reports, personnel such as Regional Office Directors, Forest Supervisors, and District Rangers gather as much factual information as they can regarding the incidents and report their findings to appropriate Claims Officers. Special Agents or Safety and Health personnel (depending on the nature of the incident) may then investigate the incident more thoroughly. The evidence developed through extensive investigation is the basis for cases referred through the OGC to the Department of Justice for possible court action. This evidence can, however, also be used to settle claims before going to court.

The Federal Claims Collection Act of 1966 (31 USC 951-953) requires Governmental agencies such as the Forest Service to attempt claims collection from those who have caused losses to the Government. The Act delineates procedures, which we call the demand-for-payment process, that should be used to settle claims. Whenever there is any doubt about specific procedures to follow, the Forest Service consults OGC field office representatives (called Regional Attorneys or Attorneys-in-Charge) for advice and recommendations.

[17] *Estimate from Michael J. Danaher, OGC Attorney, in a telephone conversation, October 16, 1981.*

[18] *Estimate from Ernest V. Andersen, Group Leader, Law Enforcement, USDA Forest Service, Washington, DC, in a telephone conversation, November 13, 1981.*

Settlement Before Cases Reach Court: Demand-for-Payment Process[19]

The Forest Service Chief has designated Regional and Research Support Services personnel as Forest Service Claims Officers. (In the Washington Office, the Group Leader of Washington Office Fiscal Support serves as Claims Officer.) Subject to requirements of the Regional Forester or Station Director, these Claims Officers are authorized to issue "demand for payment" letters for claims in any amount more than $35 and to accept payments settling those claims.[20] Regional Claims Officers can likewise authorize Forest Administrative Officers such as Forest Supervisors to make claims of $10,000 or less, issue demand letters, and accept payments. Forest Supervisors can, in turn, authorize District Rangers to issue demand-for-payment letters and accept payments for $600 or less. Claims under a Region's or Station's authority are referred to the Chief's office for processing if Claims Officers are uncertain about appropriate action to take, if Forest Service policy is involved, or if claims exceed predetermined dollar amounts.

1. **Initial demand-for-payment letter.**[21] Based on investigative reports, the first demand-for-payment letter informs a debtor of the reason for and the amount of indebtedness, the date payment is due, the interest that will be charged for late payment, and other consequences of the debtor's failure to cooperate.

   The Forest Service official (e.g., Claims Officer, Forest Supervisor, District Ranger) who sends the

[19] *The Forest Service uses some special procedures for administratively handling timber breach of contract disputes before going to civil court; they are outlined in FSM 2433.7 and 2433.8.*

[20] *In some circumstances, claims are immediately referred to the OGC, e.g., when fraud is suspected or when someone violates antitrust laws. Collection action is not initiated on claims less than $35.*

[21] *When a U.S. Magistrate or other judicial authority has sentenced an offender in a criminal case to pay the U.S. Government for damages, demand-for-payment letters are not necessary. The Forest Service's role in such circumstances is to alert the judicial authority promptly when the offender has or has not paid.*

demand letter and bill includes evidence to support the Agency's claim, e.g., an itemized bill for completed repairs; the value of the damaged or destroyed property immediately before the incident, less salvage value, if any. (See FSM 6572.25a "General Resource Damages.")

2. **Followup billing**. If the Agency does not receive the debtor's payment by the requested date, the appropriate Forest Service officer pursues collection with aggressive followup billing, unless a response to the first demand indicates that further letters would be futile. Usually, progressively stronger written demands, issued at 30-day intervals, are sent to the debtor. (See 4 CFR 102.2.) Each followup bill includes the interest added and the new payment due date.

   Several Forest Service Claims Officers have estimated that only 10 to 20 percent of demand letters result in compensation for losses.

3. **Personal interview**. The Federal Government expects agencies such as the Forest Service to conduct personal interviews with their debtors whenever feasible. This step may occur at this point or earlier.

4. **Small Claims Court**. Recently, the Department of Justice and the OGC agreed that the Forest Service has the authority to settle smaller claims in Small Claims Court, in part because it's so costly to take a case to Federal court (at least $600 for even a simple, uncontested claim). Small, unpaid claims can, therefore, be taken to Small Claims Court if the demand letters have been ineffective. Depending on the State, small claims settlements are generally between $150 and $1,000. Because limitations and procedures differ in various courts, Forest Service officials obtain advice about Small Claims Courts from their nearest OGC office.[22]

5. **Referral to OGC Field Office**.[23] If a Claims Officer has attempted the collection methods above, and payment, compromise, suspension, or termination of those debts has not occurred,[24] then he or she refers those claims to the Regional Attorney/Attorney-in-Charge in the local OGC field office for advice. All requests for legal action sent to the OGC include the following (see FSM 6572.18a):

   a. a summary of action already taken to collect or compromise the claim;

   b. proof that payment demands and compromise efforts were made by the Forest Service;

   c. evidence that demands for payment from surety or insurance firms (or statements of nonapplicability) were made by the Forest Service;

   d. a statement that a personal interview with the debtor was held to collect or compromise the claim (or, if the interview was omitted, the reason for the omission);

   e. the current address(es) of parties involved (or evidence that sufficient efforts were made to locate missing persons);

   f. current credit data showing that collection is possible.

   Except for breach of contract cases, if the field office OGC attorney believes that a legal proceeding is likely to result in reimbursement to the Government for damages, he or she can refer certain claims directly to an appropriate U.S. Attorney. These claims are either $100,000 or less, if they arise from such activities as unauthorized timber cutting and human-caused fires, or $60,000 or less, if they arise from other activities. Claims greater than these figures must be referred to the Chief of the Forest Service.

6. **Referral to the Chief's Office**. After the OGC field representative has given a recommendation for action on claims more than $100,000 or more than $60,000, the Claims Officer sends those claim files to the Chief. The claim files include the material discussed in Step 5, the original copy of the investigative report, and the OGC field office representative's recommendation for action.

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[22] *For a clear explanation of procedures to use when filing a claim in a Small Claims Court, see* Consumer Reports, *November, 1979, 44(11): 666-670; and/or* The 1979 Buying Guide Issue of Consumer Reports, *December, 1978, 43(12): 357-358.*

[23] *As of this writing, the USDA is considering using private collection agencies to collect certain claims. If these services are used, it is likely that those claims appropriate for referral to collection agencies will not be referred to the OGC for legal action unless the collection agency is also unable to get a debtor to pay.*

[24] *Forest Service Claims Officers can compromise, suspend, or terminate collection actions, except when civil claims involve fraud, exceed $20,000, or the debt is clearly covered by insurance or bond. When termination or compromise of a debt between $10,000 and $20,000 is being considered (or doubtful claims under that amount), Claims Officers obtain the advice of the appropriate OGC office. Claims Officers do not have to contact the OGC about most claims under $10,000. (See FSM 6572.15a and 6572.16a.) Only the Departments of Justice and Treasury have authority to accept a debtor's offer of compromise when the claim exceeds $20,000. (See FSM 6572.15b.)*

7. **Referral to the OGC Washington Headquarters by the Chief.** The Chief examines the claim files referred to the Washington Office and generally follows the OGC field representative's advice in referring the claim to the Washington OGC.

8. **Referral to the Department of Justice by the OGC.** If the OGC determines that the facts developed in the request for legal action can support a lawsuit in civil court, the OGC promptly refers the claim to the Department of Justice.

9. **Action by the Department of Justice.** The Department of Justice determines whether or not a lawsuit is warranted. If legal action is taken, a U.S. Attorney initiates a lawsuit in a U.S. District Court. The process that is followed is the same as that outlined in Appendix V, starting with Step 2, "Filing a lawsuit."

The Forest Service's role in a lawsuit differs according to the case. For instance, an employee having first notified a supervisor of an incident resulting in a claim may be called on to act as a witness as might employees who investigated the case. Special Agents may assist U.S. Attorneys through the entire civil process—from serving subpoenas and gathering evidence to locating witnesses who can testify against the debtor.

If legal action is not taken, the Department of Justice may attempt an administrative collection or compromise, close the case, or advise the OGC of additional action that should be taken by the Forest Service.

CRIMINAL PROCESS

The criminal process is a method by which the legal system handles individual criminal cases; it's an orderly progression of events, beginning with a detected and reported crime and concluding with the unconditional release of a law violator. It is designed to: (1) punish proven law violators, (2) remove dangerous people from the community, (3) deter others from criminal behavior, and (4) transform law breakers into law-abiding citizens (Appendix VI) (Chamelin *et al.* 1975). (For a discussion of the similarities and differences between the civil and criminal processes, see Appendix VII.)

Most crimes, originally determined by English common law, have now been defined by statute. These statutes, both State and Federal, declare what conduct is criminal *and* prescribe the punishment to be imposed (via the criminal process) for such conduct. (Title 18 of the United States Code contains Federal crime statutes. See Appendix II for two such examples.) A crime, therefore, is an act (or failure to act) violating a criminal law that is punishable, upon conviction, by (1) fine, (2) imprisonment, (3) removal from office, (4) disqualification to hold any office of honor, trust, or profit and/or (5) death (Black 1979). Even though a crime may and often does involve injury to some individual, it is considered an offense against the public and is punishable as such.

Although crimes can be classified in any number of ways, they are most often divided into felonies and misdemeanors.[25] The distinction between the two is based either on the type of institution in which an offender may be incarcerated or the length of imprisonment (or sometimes a combination of both). Federal and many State statutes define a felony as an offense punishable by death or by imprisonment for more than 1 year in a Federal or State penitentiary. Examples of felonies include murder, rape, aggravated assault, incendiarism, kidnapping, and burglary. Likewise, under Federal and most State statutes, crimes that are not felonies are generally called misdemeanors. Most are punishable by fine or imprisonment for 1 year or less in a municipal or county jail. Sometimes misdemeanors are classified as high or low (petty offense) misdemeanors. High misdemeanors, carrying more than a 6-month sentence and larger fines, are considered serious, while low misdemeanors are considered less serious. The penalty for the latter does not exceed 6 months in jail or a fine of $500, or both. Examples of misdemeanors are criminal trespass, allowing a fire on National Forest land to escape control, disturbing the peace, assault, and vehicular homicide.

Because the subject of crime and criminal law is too extensive to cover in this publication, we suggest the reader consult criminal justice texts for additional information. (Two such texts are on the recommended reading list at the end of this publication.) These books discuss in greater detail subjects such as types of crime, general doctrines and principles of criminal law, elements of a crime (act and intent), parties to a crime (principals and accessories), capacity to commit crime, and rules of evidence.

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[25] *Crimes are also commonly classified into the following categories: person or property; street, organized, or white collar;* mala in se *or* mala prohibita; *infamous or not infamous; major or petty; common law or statutory; involving moral turpitude or not involving moral turpitude.*

The Forest Service and the Criminal Process

Criminal acts against the Forest Service and consequently the public, i.e., felonies and misdemeanors including petty offenses, are found in Title 18 USC, Crimes and Criminal Procedure, and in 36 CFR 261, Prohibited Acts. Crimes involving fire are defined by 18 USC 1855—Fire willfully set to timber, brush, or grass—(a felony), l8 USC 1856—Fires left unattended and unextinguished—(a petty offense misdemeanor), and 36 CFR 261.5, fire regulations (also petty offense misdemeanors).

Forest Service involvement in the criminal process —which the Agency defines as a proceeding instituted and conducted for the purpose of fixing guilt for a crime already committed and punishing the offender—is limited primarily to Steps 1-3 of the process (Appendix VI). That is, the Agency focuses on detecting and reporting criminal offenses, identifying offenders, investigating criminal acts, arresting suspects if necessary and taking them into custody, issuing violation notices, serving summonses, and filing complaints.

A violation occurs when any person commits an act or omission in violation of Federal, State, county, or municipal statutes, regulations, or ordinances related to the National Forest System. Fire violations fall within three basic categories: (1) the willful setting of a wildfire or the deliberate burning of a building or vehicle regardless of whether it escapes to surrounding lands, (2) negligently causing a wildfire, or (3) violating statutes or regulations pertaining to wildfire prevention.

Forest Officers initiate the criminal process in cases involving violations of these statutes, regulations, or ordinances if (1) the violations were committed in their presence on National Forest land or if (2) witnesses sign statements that crimes were committed in their presence and that they're willing to testify in court. Once the crimes have been detected and reported, Forest Officers have several alternatives.

If a violation was committed in the presence of a Forest Officer and immediate action must be taken to prevent serious damage, the violator's escape, or loss of material evidence, or if a Forest Officer has probable cause to believe a felony has been committed or is about to be committed, the Officer can make an arrest *without* a warrant if it can be done reasonably safely. Although all Forest Officers have the authority to make arrests for violations of Federal statutes and regulations relating to the National Forest System, arrests are normally made by Special Agents or other specially trained and equipped Forest Officers. In most cases Forest Officers are encouraged to initate action leading to an arrest *with* a warrant. This involves, in coordination with OGC, filing a complaint—a formal, written accusation charging that an individual has violated a Federal statute or regulation—with a U.S. Magistrate who, in turn, will usually issue a warrant for the suspect's arrest. (A summons may also be issued at this point, in lieu of arrest.) When the warrant is served by a U.S. Marshal, a Special Agent, or a Law Enforcement Officer (or the violator surrenders voluntarily after receiving the summons), the suspect is taken without unnecessary delay before the nearest U.S. Magistrate within the judicial district where the offense occurred. If the Magistrate is unavailable the arrested prisoner may be held in temporary custody in a city or county jail approved for Federal prisoners until his or her initial appearance before a U.S. Magistrate. (For a continued explanation of the process see Step 6 and following in Appendix VI.)

For most observed violations that are petty offense misdemeanors, Forest Officers issue verbal warnings, written warnings, or violation notices. Verbal or written warnings are generally given if violations occurred due to inadvertance, lack of understanding, or misinformation.[26] If warranted, a violation notice will normally be issued in person to the violator at the time the petty offense occurs. If circumstances dictate otherwise, however, the violator may be cited at a later time (or the Forest Officer may sign a complaint before a U.S. Magistrate).

Petty offense violations can be disposed of by paying fines set by the court or through mandatory or voluntary appearances before U.S. Magistrates. If violators pay fines by mail, their cases are closed. If they opt to or are required to appear before a U.S. Magistrate rather than pay fines, they will be tried summarily, found guilty or not guilty, and sentenced. (If a person refuses to be tried by a U.S. Magistrate, he or she has the right to be tried in a U.S. District Court.) When violators do not pay their fines by mail or appear in court, the court either sends letters demanding payments or issues summonses to appear in court. If the violators do not respond to the letters or summonses, warrants will be issued for their arrests. They will be

[26] *Discretion may not be used when a violation of 36 CFR 261 results in loss or damage greater than $100, when acts are clearly malicious, willful, or deliberate, or when the safety or rights of others are jeopardized. In petty offense cases where the violator aggravates the situation through abusive behavior, the Forest Officer has the discretion to cite the violator for a mandatory appearance before a U.S. Magistrate.*

arrested by U.S. Marshals and taken before the nearest U.S. Magistrate for bail hearings. Trial dates will also be set at that time.

In most instances, the Forest Service initiates prosecutions by issuing violation notices, but in addition to the other means such as immediate arrests or filing complaints in coordination with the OGC, Forest Officers can prepare written case reports, based on their investigations of violations,[27] for a U.S. Attorney to review.[28] Liaison with the U.S. Attorney is made through an OGC field office, although local procedures approved in advance by the OGC may allow Special Agents and Law Enforcement Officers to contact the U.S. Attorney directly in criminal cases. If the U.S. Attorney decides to prosecute, he or she will either file an information, charging an individual with violating a Federal statute or regulation, or seek a grand jury indictment. In the latter case, the Forest Officer who prepared the case report for a particular violation will be required to testify before a grand jury. If the grand jury returns a true bill based on the Forest Officer's testimony, a court trial will be scheduled. Further action by a Forest Officer, at the discretion of the U.S. Attorney, may involve his or her appearance as a witness during the trial. U.S. District Courts are used to try felonies when a suspect refuses to be tried by a U.S. Magistrate or when a U.S. Magistrate is not designated to try a violation for a particular criminal act. Other cases, generally petty offense misdemeanors, are usually handled by U.S. Magistrates, although in some districts they can also try and sentence people charged with high misdemeanors.

[27] *Forest Service investigations (searches for facts and evidence) are initiated and continued until responsibility for violations is established or until every reasonable lead has been exhausted. Normally, violations of both Federal and State laws pertaining to the National Forest System will be enforced and investigated by the Forest Service. Violations of State or local laws will be referred to the appropriate State or local law enforcement agency and prosecuted by State or county prosecutors. Wildfires are investigated by employees trained to determine the fire's origin, cause, and person(s) responsible, as well as other elements necessary to establish criminal and civil liability. A Special Agent is notified immediately of a wildfire if suppression costs are expected to exceed $40,000 and/or the wildfire is suspected of being willfully set.*

[28] *Cases not handled by violation notices are submitted through an OGC attorney to a U.S. Attorney who authorizes or declines prosecution of each. Besides prosecuting cases for the Forest Service, U.S. Attorneys also assist Forest Service Officers in preparing or securing Federal complaints, information, or warrants.*

FOREST SERVICE LAW ENFORCEMENT, WILDFIRE VIOLATIONS, AND FIRE PREVENTION

Although the Forest Service interacts in varying degrees with all of the components of the American legal system—legislative groups, legislated laws, enforcement agencies, and courts—most of its activities are concentrated under the realm of law enforcement and enforcement agencies. This section, therefore, will begin with an overview of Forest Service law enforcement and end with an appraisal of wildfire violations and the role of law enforcement in wildfire prevention.

Overview

Law enforcement is not the primary mission of the Forest Service. Rather, the Service is a resource management agency that uses law enforcement to enhance its management activities. As a supportive function within the Agency, Forest Service law enforcement has a unique history and place in National Forest management. The early-day forest rangers, armed and riding horseback over mountain trails, were essentially custodians of the newly created National Forests, protecting them against wildfires, game poachers, timber and grazing trespassers, and exploiters (Bergoffen 1976). As the need for law enforcement seemingly decreased in subsequent years, it became a lower priority on the National Forests, and the "cowboy" image gave way to the less conspicuous, uniformed steward of the land.

Until the late 1960's, land managers with resource-related backgrounds were attuned to managing environments that were relatively free of people and of illegal or unauthorized activities (USGAO 1982). As a result, law enforcement continued to receive a relatively low priority. It was not only difficult to prosecute cases in court,[29] for example, but Forest Service law enforcement advocates and practitioners were often looked upon with disfavor.

Since the late 1960's, however, increasing numbers of people have been attracted to Federal land for a number of reasons including the forests' valuable natural resources, remoteness, and recreational opportunities. With changing technology, population increases, and changing times, the magnitude and seriousness of crimes have been increasing on National Forests (USGAO 1982).

[29] *Cases went before U.S. Commissioners who gave them low priority (U.S. Magistrate positions weren't created until 1972), and a system of collateral forfeiture had not yet been instituted.*

Ralph Dyment, Region 4 Special Agent, attributes the rapid increase in crime on National Forests to "more misfits and loners - those people who choose to live outside the law - ... trying to make their homes in National Forests" (Eldredge 1981). Dyment also cited the increased illicit use of National Forests for the exchange, cultivation, and transportation of narcotics. A recent U.S. General Accounting Office (GAO) report (March 1982) concurs with Dyment. According to the report, land managers are increasingly faced with the following illegal or unauthorized activities: (1) crimes against people and their property (e.g., burglary, larceny), (2) marijuana cultivation, (3) trespass (e.g., unauthorized occupancy, paramilitary activities, garbage dumping, grazing violations, cultural artifact theft), and (4) timber thefts.

Even with this increase in crime, a wide range of views on law enforcement in the Forest Service still exists today. The traditional approach dictates keeping a low profile, which means in some cases doing nothing, and views law enforcement as little more than "meter maid" duties and responsibilities. Indicators of such an approach in the past include the relatively few people involved in law enforcement, the lack of carefully structured training standards, and the over-extended use of Level II and III Forest Officers beyond their training capabilities.

A more recent approach dictates strengthening law enforcement programs and activities and increasing their visibility.[30] The trend, in fact, appears to be swinging from the "low profile" policy to realizing the vital role of law enforcement in the Forest Service, seeing a need for armed officers, and understanding the law enforcement/Good Host relationship. Land managers are beginning to realize that the host program is not negated by good law enforcement. On the contrary, when the Forest Service prevents individuals from committing unlawful acts on forest land, it is ensuring that the goals of protecting life, property, and the constitutional rights of citizens are attained.

Even though the Forest Service perceives the need for improved law enforcement efforts, some problems remain:

- Although the Forest Service has spread responsibility for law enforcement throughout the Agency, law enforcement activities are handled by relatively few Forest Service personnel; of these, only a small number are thoroughly trained. Of the nearly 50,600 permanent, career-conditional, and temporary employees working for the Forest Service in the summer of 1981, only 13 percent had law enforcement training. Excluding those with Level II and III training (most spend only 5 to 20 percent of their working hours in law enforcement activities), the ratio of law enforcement personnel to all the other Forest Service employees drops even lower. The 485 Law Enforcement Officers (Level IV's) comprise less than 1 percent of the total employees in the Forest Service (1.5 percent if temporary employees are excluded), and the 100 Regional and other Special Agents, the only full-time enforcement personnel, constitute less than 1 percent of the employees (including or excluding temporary employees).

- Some Forest Service law enforcement employees have cited the limited number of hours most personnel spend in training and then in actual enforcement activities as reasons for weak law enforcement in the Forest Service and for not meeting Good Host program objectives. For example, more than half of those given Level II and III training are summer employees. Although some of these employees return a second or third year, many do not. Law enforcement instructors have also observed that when many permanent employees begin Level III training, they've forgotten the basics learned in Level II. As a result, many of the additional 80 hours of training are spent relearning

[30] *Special Agent and Law Enforcement Officer positions, for example, are relatively new. Special Agent positions on the National Forests were originally created to deal with wildfire problems in the South (Region 8 had the first Special Agents in the 1950's) but have since become more diversified. Although in the early 1960's agents were placed in Forest Service Regional offices, they did not have positions in the Washington Office until the early 1970's. Special Agents have increased from approximately 30 in 1974 to 100 in 1982.*

Law Enforcement Officer positions were finally established in 1972 in response to a need for professionally trained people (for generalists as opposed to specialists) to handle recreation problems on the National Forests. Their numbers have increased from zero in 1971 to 485 in 1981.

According to one Regional Special Agent, pre-1978 law enforcement training standards were vague, ambiguous, and inadequate; a 3-day (24-hour) training session, for example, was considered enough background to write a violation notice, and a 2-week (80-hour) session, including the 24-hour session, was considered "advanced" training. In 1978, however, more rigorous minimum training standards for Level I-IV Forest Officers (see FSM 5370) were developed and implemented to ensure adequate quantity and quality of training for people with law enforcement responsibilities.

the lessons of the first 40 hours. Employees forget their earlier training primarily because they spend few working hours in enforcement activities—their duties consist mainly of forest-related field work.

According to the 1982 GAO report:[31]

- Management constraints, e.g., travel, vehicle, and duty restrictions, are limiting efficient and effective enforcement activities.
- Although factors, including limited Agency resources and remote land, contribute to both the rise of crime on National Forests and the inability of the Forest Service to meet its enforcement responsibilities, the lack of management emphasis also aggravates these problems. While some managers have been slow to recognize and deal with enforcement-related problems, others do not believe that a serious problem exists. This is due in part to the lack of data on the magnitude and seriousness of illegal and unauthorized activities on public lands. (Unlike other Federal land management agencies, the Forest Service has developed a reporting system, called the Law Enforcement Management Reporting System [LEMARS], approved for use in October, 1981. Because the system is so new, however, statistics are just being developed.) Without such crime data, it's difficult for management at any level to determine the magnitude of the crime problem and assess the effectiveness and efficiency of law enforcement efforts.
- The Forest Service has, at a minimum, the power to impose and enforce regulations intended to prevent interference with proper management and utilization of public resources. Although the Agency's law enforcement responsibilities are in the regulations (and elsewhere), land managers do not consistently use their law enforcement responsibilities and authority. Furthermore, because the Forest Service does not have uniform, nationwide law enforcement policies, it allows Regional managers to set their own local policies. Marijuana cultivation, for example, may be treated one way by one Region and a different way by another Region; one Region can decline law enforcement responsibilities for marijuana cultivation, while another may cooperate with State and local law enforcement officials in marijuana eradication efforts.
- Citing one problem in particular, the GAO report maintains that Forest Service officials do not always enforce trespass statutes and regulations. The magnitude of trespass occurrences is not known, but Forest Service managers and documents indicate that trespass violations are increasing. These violations result in restricted public and employee access, environmental degradation, revenue loss, increased costs to the Government, and endangered public and employee safety.
- Impediments to gaining greater Forest Service commitment to the law enforcement program include the general lack of (1) understanding of the Forest Service's objectives and policies, (2) knowledge of the actual on-the-ground situation, and (3) confidence in the ability of law enforcement to complement management's other programs.

Given these problems, the GAO report suggests that:

1. More management emphasis is needed to enforce the present statutes and regulations in order to halt the widespread and increasing incidence of illegal and unauthorized activities on National Forests.
2. In order to improve enforcement efforts, the Forest Service must clarify the field offices' critical role by defining the law enforcement obligations and responsibilities of each employee.
3. Existing regulations should be revised to deal specifically with current crime situations, e.g., marijuana cultivation, timber theft, and trespass.
4. The level of law enforcement effort devoted to preventing and controlling criminal activities should be increased.
5. Where feasible, workforce, resource, and policy constraints impeding law enforcement efforts should be removed and emphasis and support should be given to preventive patrolling, providing vehicles when needed, and assuring adequate coverage by law enforcement personnel through improved duty assignments.

In addition to the GAO recommendations, some Forest Service employees have expressed their desires to see personnel with law enforcement duties and responsibilities attain professional status, to make law enforcement a separate function or division within the Forest Service (it's currently under Fiscal

[31] *The objectives of the GAO review and subsequent 1982 report were (1) to identify the nature and extent of illegal and unauthorized activities on National Park Service, Bureau of Land Management, and Forest Service lands in Southwestern Oregon and California and (2) to assess the agencies' efforts to combat unlawful activities. Although the GAO study was conducted in a limited geographic area, its findings pertaining to the Forest Service can be generalized to the Service's law enforcement efforts outside Oregon and California.*

Management), to increase the number of Law Enforcement Officers (Level IV's) in the Agency instead of Level II's and III's, and to have a Special Agent assigned to every National Forest.[32]

Counteracting such changes is the strong desire to avoid a "police" agency in the Forest Service. As a resource management agency dealing increasingly with people and their criminal activities, the Forest Service must strike a balance between the need for increased law enforcement efforts to achieve its goals of prevention and protection of people, property, and resources, and the concern over becoming a "police" agency and presenting an undesirable public image.

The Role of Law Enforcement in Wildfire Violations

Forest Service law enforcement efforts are not equally divided among the different functional areas. For example, nationally, 57 percent of the Agency's law enforcement effort is directed at forest recreation. Although fire receives significantly less enforcement emphasis than recreation (7.5 percent), it's still higher than other activities such as occupancy (6 percent), timber, range, and wildlife (4 percent each), employee protection and claims (3 percent), and archeology (2 percent).[33] These percentages may change, however, as the Forest Service responds to criminal activities developing on the National Forests. While the Service is calling for increased enforcement efforts in timber, employee protection, claims, and archeology, for example, it recommends that in upcoming years law enforcement efforts directed at fire remain the same.

Wildfires were not mentioned in the main body of the GAO report (1982) as a serious law enforcement problem on the National Forests. Information from a number of wildfire reports[34] indicates that, although incendiary fires (the worst human-caused fire problem) have increased dramatically on U.S. wildlands from 1972-1980, they have remained fairly static on the National Forests over the last several years (an average of 32 percent of human-caused fires on Forest Service land are caused by incendiarists).

The current status of Forest Service law enforcement efforts directed at wildfire violations is summarized below:[35]

All Reported Violations vs. Wildfire Violations

Ninety-three percent of all reported violations on National Forests were petty offense misdemeanors; 4 percent were high misdemeanors, and the remaining 3 percent were felonies. Approximately one-fourth of the petty offenses and two-thirds of the felonies and high misdemeanors were violations of Forest Service fire statutes and regulations.

More than half the cases involving all reported violations of Forest Service statutes and regulations were solved and completed; approximately one-fourth were completed but unsolved, and the remaining were either incomplete or not acted on. Fire violations comprised one-fourth of the solved and completed cases, one-third of the completed but unsolved cases, 30 percent of the incomplete cases, and 40 percent of the cases in which no criminal action was taken.

Although the disposition of most cases (71 percent) is unknown, 29 percent of the cases resulted in a guilty verdict (9 percent of those were for fire violations), one person was found guilty of a nonfire offense, and 11 cases, none of which involved fire, were dismissed.

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[32] *Because many forests do not have a Special Agent assigned to them, calling in an agent when special investigative assistance is needed is an unplanned expense. As a result, some forests needing a Special Agent's expertise seldom receive it. Thus, some law enforcement personnel have suggested assigning one Special Agent to each National Forest that regularly needs such services and establishing "zone agents," responsible for more than one of the National Forests that have less severe crime problems and lower case loads.*

[33] *Each percent is equivalent to 16 person years. Information courtesy of Ernest V. Andersen, Group Leader, Law Enforcement, USDA Forest Service, Washington, DC.*

[34] *Information was taken from both the USDA Forest Service* Wildfire Statistics *(1972-1980) and from the USDA Forest Service* National Forest Fire Report *(1975-1980).*

[35] *LEMARS (Law Enforcement Management Reporting System) data used to compute percentages were supplied by the Forest Service Washington Office. Because LEMARS was recently formulated and implemented, data are incomplete; some Regions are not yet on the system, some are just entering it, and others have supplied substantial amounts of data. Data supplied by Regions 2, 5, and 9 from 1979-1981, the most reliable at this time, were used to compute the percentages here. Because the data are incomplete, our results are tentative.*

Violations of Forest Service Fire Regulations (Subpart A, 36 CFR 261.5a-.5f) and Orders (Subpart B, 36 CFR 261.52a-.52k)

Although 18 percent of all reported violations of Forest Service regulations involved illegal fire activities, less than one-fourth (21 percent) of these fire violations resulted in fines. (Persons responsible for the remaining 79 percent of the fire violations were not identified.) One-tenth of the warning notices for violations of Forest Service regulations were issued for fire offenses.

Because the number of reported violations of fire regulations are higher than one would expect, given the amount of law enforcement effort directed at the wildfire problem (7.5 percent), we speculate that:

(1) even though the law enforcement effort is relatively small, it's highly efficient, directed at specific problems and targets,
(2) the wildfire law enforcement effort could be larger than the data indicate,
(3) the wildfire problem is greater than the enforcement emphasis given, and/or
(4) law enforcement personnel are more apt to cite and/or report fire violations than other types of infractions.

Three types of unlawful activities accounted for almost 90 percent of the violations of Forest Service regulations (Subpart A, 36 CFR 261.5a-.5f):

(1) Leaving a fire without completely extinguishing it (261.5d) (54 percent of the violations).
(2) Carelessly or negligently throwing or placing any ignited substance or other substance that may cause a fire (261.5a) (17 percent of the violations).
(3) Burning without a permit (261.5c) (17 percent of the violations).

Two types of unlawful activities accounted for 80 percent of the violations of Forest Service orders (Subpart B, 36 CFR 261.52a-.52k):

(1) Building, maintaining, attending, or using a fire, campfire, or stove fire (261.52a) (42 percent of the violations).
(2) Going into or being on an area temporarily closed to public use (261.52e) (38 percent of the violations).

Because violations of Subpart A and B fire regulations accounted for most of the reported fire offenses, wildfire prevention activities could be targeted at these particular problem areas. This may involve more rigorous preventive patrolling by law enforcement personnel and added efforts to educate the forest-using public about fire hazards and wildfire statutes and regulations.

Violations of Title 18 USC 1855 and 1856

Although 40 percent of the reported Title 18 USC offenses were violations of fire statutes 1855 and 1856, only one person was fined (under 18 USC 1856) for criminal activity. The remaining offenders were not identified.

Violations of State and Local (Non-Federal) Laws

Unlawful fire activities accounted for most (87 percent) of the reported violations of non-Federal laws.

Like the violations of fire regulations discussed above, the number of Federal, State, and local wildfire law violations are higher than one would expect given the amount of law enforcement effort expended. It's possible, therefore, that the reasons for these higher numbers are similar to those for reported violations of fire regulations.

The Role of Law Enforcement in Wildfire Prevention

The role of law enforcement in wildfire prevention seems a circuitous one. Rather than law enforcement being preventive, it seems to attack the problem *after* it has occurred rather than before, in a sense, "locking the barn door after the horse has been stolen." And, yet, recognizing that the ultimate goal is prevention, Ralph Dyment asserts that

> one good case publicized widely is worth ten cases that do not receive publicity. The deterrent level value of a case is its real worth, not the cost of investigation versus fine imposed. Some Forest Service personnel are reluctant to prepare a case when the result would be only a small fine. The cost-benefit ratio appears more favorable when you consider that a large number of similar crimes can be prevented by completing and publicizing this one case (Eldredge 1981).

Violations of Forest Service statutes and regulations can also be prevented by other "postcrime" law enforcement activities. Taking a somewhat different approach, for example, in describing the roles of law enforcement in wildland fire prevention, Ernest Andersen (1980) discusses some of the more important links between "postcrime" activities and prevention programs. The first and perhaps most important link is thorough, professional investigation of fire causes to establish the who, what, when, where, and how elements of a crime. These investigations, "the cornerstone of an effective, efficient fire prevention program," provide the basic information used in pre-

paring court cases, in evaluating fire prevention program success, and in identifying new trends in and results of demographic changes.

And what of the role of law enforcement personnel in this process? According to Andersen (1980), their role is to advise managers about: the reliability of investigative results, the feasibility and probability of success in eliminating fires by specific causes, the applicability of statutes and regulations to specific problems, and the courts' interpretations of statutes and regulations.

Given this input,

> along with that of other specialists, managers can develop a wide array of alternatives that are targeted at preventing those fires that are most likely to cause significant resource damage. Fire prevention program ... elements can be selected based on their probability of success and on resource losses prevented. Economic and personnel resources required can be measured against the probability of success of each alternative. Expenditures can be targeted and concentrated on those specific causes, locations, and times that would result in large negative resource value changes rather than [be] targeted at preventing numbers of fires (Andersen 1980).

Thus, Forest Service law enforcement should play an important role in wildfire prevention. Its role, however, will probably never be as large as that of prevention education and, in fact, seems relatively small when compared to public information and education efforts currently directed at wildland users. And, yet, if used wisely and efficiently as a complement to other prevention efforts (e.g., education, engineering, hazard reduction), Forest Service law enforcement, as part of the American legal system, can have potentially significant impacts on wildland fire prevention effectiveness.

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We're also very grateful to Ernest V. Andersen and Wayne Wilson, Washington Office Law Enforcement, and to Freeman L. Brock, Jr., Washington Office Fiscal Support, for their generosity in answering our numerous questions and reviewing our work for technical accuracy. We also acknowledge and thank Albert J. Simard, our Project Leader, and Fred McCauley, Forestry Aid, for their help in producing the diagrams used to illustrate this publication.

Finally, we thank the many police department employees, judges and court clerks, probation officers, prosecutors, and Forest Service personnel who clarified legal procedures and processes for us. We could not have accomplished this momentous task without their gracious help and support.

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RECOMMENDED READINGS

Bahme, Charles W. *Fire Service and the Law.*

Bahme, both a deputy fire chief with the Los Angeles Fire Department and an attorney-at-law, used his expertise in these two areas to write this book, a successor to his *Fireman's Law Book.*

Even though *Fire Service and the Law* is designed to teach legal principles applicable to fire fighters and fire departments, it can be useful to Forest Service readers because of its emphasis on fire. The author gives a brief introduction to the law, to civil and criminal actions, and to the judicial system. A useful chapter on "Procedural Pointers" describes the criminal process, from making arrests to testifying on the witness stand. Because much of the book deals with problems and procedures unique to municipal fire departments, we recommend borrowing the book from a library rather than purchasing it.

Black, Henry Campbell. *Black's Law Dictionary.*

This dictionary has more than 10,000 entries that not only thoroughly define legal terms but also refer to specific cases which you can consult for additional background when trying to understand a particular concept. Entries also reflect the growth of Federal legislation and agencies.

Unfortunately for the layperson, not all terms are defined as simply as they could be. You may have to read several columns (sometimes several pages) of explanations and historical background to obtain an understanding of some of the definitions. Nevertheless, we highly recommend it as a resource book.

If you need a comprehensive reference book (more than 1,500 pages) to clarify legal terminology, this is the book to purchase; despite its size, its price is reasonable (less than $20 at the time of this writing).

Chamelin, Neil C., Vernon B. Fox, and Paul M. Whisenand. *Introduction to Criminal Justice.*

This book examines—from a systems perspective—the interrelations between crime and the police, courts and corrections. According to the authors, the

> text is divided into three major sections to follow the logical "input, process, output" model of a system. It begins with a general overview of the criminal justice system and the scope of the crime problem, and proceeds to critically examine historical perspectives; contemporary issues; the current state-of-the-art; the interrelationships of the police, law and the courts; and the correction-related elements of the criminal justice system.

The book is well organized and well written. It provides an excellent, detailed description of the criminal process and offers one of the best discussions of corrections that we could find. Because the book deals with so many aspects of the legal system as we've defined it, we recommend purchasing it for your resource library.

Dolan, Edward F., Jr. *Legal Action: A Layman's Guide.*

This book deals exclusively with civil law; it thoroughly discusses the grounds for lawsuits in the first

13 chapters and ends with an excellent description of the civil process in the last four chapters. We find these latter chapters most useful. In Dolan's words, they

> discuss a wide variety of matters pertaining to the day-to-day practice of law: the court system, the attorneys . . . the steps that must be taken and the documents that must be prepared in readying a civil case for trial, and the trial itself. There is information about witnesses, testimony, evidence, jury selection, court costs, and trial procedures. And to complete the book there is a look at a case being tried in court.

We highly recommend this book. It is an excellent introduction to civil law and process, in addition to being well written, simple to read (and yet comprehensive), and easy to understand (legal terms are defined clearly and concisely). If you have an interest in civil law, it's worth purchasing.

Eichner, James A. *Law.*

This is a short and very simple but useful book (a "primer" of sorts) written for the Young Adult Library. It summarizes in less than 100 pages what other books take several hundred pages to do. Although it covers a broad range of topics on law, we particularly recommend reading the pages on civil law and procedure. Like Dolan's book, *Legal Action: A Layman's Guide*, it is well written, simple to read, and easy to understand. The author is sparing with words and yet gives the first-time student of law a comprehensive introduction to the subject.

Office of the Federal Register. *The United States Government Manual.*

This publication is the official handbook of the Federal Government. It provides information on all three branches of Government (legislative, judicial, and executive), ranging from the structure of each branch to individual administrative agencies' programs. It also lists principal departmental officials, gives the dates when departments, agencies, etc., were established, and names the branch of Government that gave each agency authority.

We find this book particularly useful to those needing information about Federal law enforcement agencies and the courts. It not only describes these agencies in detail but also provides telephone numbers and addresses of offices to contact if the reader needs additional assistance. For the most recent copy of the *Manual*, write to: Office of the Federal Register, National Archives and Records Service, Washington, DC 20408.

Rosenbauer, Donna L. *Introduction to Fire Protection Law.*

Rosenbauer, an attorney-at-law, wrote this textbook primarily "to help make students more aware of some of the legal considerations involved in a career in the fire service" and "to help increase student awareness of the general areas of the law they may have to deal with."

Because it gives a general overview of law, it may be helpful to Forest Service law enforcement personnel who wish to understand the bases of our statutes and regulations. She includes detailed chapters on torts, criminal law and procedure, and administrative law and procedure. Finally, she includes case studies that demonstrate how law affects the fire service.

This book is not particularly easy to read and it's poorly organized. We recommend that you do not purchase the book but rather borrow it from a library.

APPENDIX I
STATUTES, REGULATIONS, ORDERS, AND NOTICES

A.—The United States Code, the United States Statutes at Large, and the United States Code Annotated.

1. United States Code (USC). The Code contains Congressional laws and amendments arranged by chapters, subchapters, sections, and subsections. In addition, historical and explanatory notes often accompany the text. The Code is completely revised and reprinted every 6 years, although intervening supplements are issued annually. One advantage of the Code is that all information on a particular subject is found in one place, including cross-references to related material. For example, most of the laws affecting the National Forest System are found in Title 16, Conservation; most criminal laws are in Title 18. Because not all Federal statutes are codified, a person may still have to consult the Statutes at Large.

2. United States Statutes at Large. The Statutes at Large contain the complete text of Federal statutes arranged in chronological order of signing or approval. They are published every 2 years, at the conclusion of each Congress.

3. United States Code Annotated. The Annotated Code updates the USC before the annual supplements are published by the Government Printing Office. It is published quarterly by a commercial firm.

Those wishing to examine specific laws can find these publications in legal offices and large libraries.

Also, the Legislative Affairs Staff in the Forest Service Washington Office will locate laws and citations on request.

B.—Forest Service Regulations, Orders, and Notices.

1. Regulations. Many regulations are formulated by administrative agencies (actually by executive department heads) to control activities of the general public. The USDA's Assistant Secretary for Natural Resources and Environment approves and issues Federal regulations affecting Forest Service programs, (although the Forest Service initially drafts the regulations for the Assistant Secretary). Forest Service regulations (a) apply to the general public (as distinguished from specific individuals or organizations); (b) specify behavior that can result in penalties enforceable in the courts; and (c) either in whole or in part, implement, interpret, or prescribe law or policy. Forest Service regulations are in the Code of Federal Regulations (CFR). (See Appendix I-C.)

2. Federal regulations also give guidelines for issuing "orders"—temporary restrictions on public activities issued by designated authorities within an agency—that have the force and effect of law. For instance, Subpart B, 36 CFR 261.50 (entitled "Prohibitions in Areas Designated by Order") authorizes Regional Foresters and Forest Supervisors to issue orders imposing regulations issued by the Secretary, which close or restrict the use of a forest or a forest development, road, or trail. Fire orders 36 CFR 261.52 include regulations that prohibit such activities as smoking or welding in a specific area for a specified period. Copies of orders must be posted in relevant offices and displayed in other locations to bring the prohibitions to public attention.

3. Notices. Notices are statements of general policy or interpretations of statutes concerning National Forest administration. Notices are published in the *Federal Register* but are not codified.

C.—Procedures for Formulating Federal Regulations.

Because a regulation or rule enacted by an agency may seriously affect many people, Congress created the Federal Administrative Procedure Act (APA) in 1946. The APA prescribes, in part, agency rulemaking procedure. First, in order to receive public comment during a given time period, an agency regulation must appear in the *Federal Register*, which is published daily. Next, interested organizations, corporations, or individuals can express their views about a regulation to the agency responsible for its content; they can demonstrate, for instance, that a regulation is unconstitutional or beyond the authority of the agency. The agency then considers suggestions submitted to it and adopts a final regulation. After the regulation is adopted, it is published again in the *Federal Register*. All Federal agencies' rules and regulations are codified and published yearly in the Code of Federal Regulations.[36]

APPENDIX II
FEDERAL WILDFIRE PROTECTION ACTS

18 USC, Section 1855. *Timber Set Afire*

Whoever, willfully and without authority, sets on fire any timber, underbrush, or grass or other inflammable material upon the public domain or upon any lands owned or leased by or under the partial, concurrent, or exclusive jurisdiction of the United States, or under contract for purchase or for the acquisition of which condemnation proceedings have been instituted, or upon any Indian reservation or lands belonging to or occupied by any tribe or group of Indians under authority of the United States, or upon any Indian allotment while the title for the same shall be held in trust by the Government, or while the same shall remain inalienable by the allottee without the consent of the United States, shall be fined not more than $5,000 or imprisoned not more than five years, or both.

This section shall not apply in the case of fire set by an allottee in the reasonable exercise of his proprietary rights in the allotment. June 25, 1948, c. 635, 62 Stat. 788.

18 USC, Section 1856. *Fires Left Unattended and Unextinguished*

Whoever, having kindled or caused to be kindled, a fire in or near any forest, timber, or other inflammable material upon any lands owned, controlled, or leased by, or under the partial, concurrent, or exclusive jurisdiction of the United States, including lands under contract for purchase or for the acquisition of which condemnation proceedings have been instituted, and including any Indian reservation or lands belonging to or occupied by any tribe or group of Indians under the authority of the United States, or any Indian allotment while the title to the same is held in trust by the United States, or while the same shall remain inalienable by the allottee without the consent of the United States, leaves said fire without totally extinguishing the same, or permits or suffers said fire

[36] *If you wish to review specific Forest Service regulations, see Forest Service Manual 1023.4. To purchase copies of individual CFR titles, write Superintendent of Public Documents, U.S. Government Printing Office, Washington, DC 20402.*

to burn or spread beyond his control, or leaves or suffers said fire to burn unattended, shall be fined not more than $500 or imprisoned not more than six months, or both.

APPENDIX III
IMPRISONMENT

Imprisonment is a "restraint upon a person's personal liberty" (Black 1979) and ranges from detaining someone forcibly in the public streets to incarcerating someone in a locked and barred cell. Places of imprisonment include jails, prisons, reformatories, penal farms, conservation camps, houses of correction, and county workhouses. While in some cases as many as half of those imprisoned in a jail are *awaiting* trial (Chamelin *et al.* 1975), we are concerned here with imprisonment *after* a person has been sentenced for committing a felony or misdemeanor.

The place of imprisonment depends upon the type of court in which the case was tried, the severity of the crime committed, the kind of correctional treatment recommended by the probation officer, and the degree of security needed. Most people convicted of misdemeanors are housed in more than 4,000 locally administered jails (Chamelin *et al.* 1975). These jails hold people for more than 48 hours but rarely over a year. (Juvenile offenders are sent to specific juvenile detention institutions in most parts of the U.S.)

State and Federal prisons (or penitentiaries), on the other hand, detain felons for more than 1 year. These institutions range from community custody institutions for first-time offenders to maximum security prisons for hard-core criminals.

Reasons for sentencing a person to imprisonment rather than to some other form of punishment (e.g., probation or a fine) are: (1) to obey laws requiring imprisonment, (2) to protect society from habitual offenders, (3) to withdraw many of the freedoms and rights to which a person is entitled in free society, (4) to discipline proven law violators, and (5) to correct, insofar as possible, the improper behavior of offenders in order to restore them to society.

APPENDIX IV
COURT JURISDICTION

Jurisdiction is basically the authority or legal power of a particular court (State or Federal) to hear and decide certain cases within a given geographic area. Without jurisdiction, no court can validly try and sentence a person (Chamelin *et al.* 1975).

According to Chamelin *et al.* (1975), jurisdiction has three components in criminal cases—territorial, personal, and subject matter. Territorial jurisdiction means that no court in any State has the authority to deal with criminal violations against the Federal Government or other States. Federal courts dispose of Federal crimes and State courts dispose of State crimes occurring within their boundaries.

Personal jurisdiction refers to the power of a court over the defendant's person (as opposed to property) (Black 1979). "In order for a court to have jurisdiction over the accused person, the presence of the accused in the courtroom is all that is required" (Chamelin *et al.* 1975). In other words, a person cannot be tried *in absentia.* Voluntary appearance and arrest are the two most common methods of ensuring a person's presence in a courtroom.

Subject matter jurisdiction is the jurisdiction of a court over a class of cases, i.e., the power of a particular court to hear the type of case before it (Black 1979). A court with limited criminal jurisdiction, for example, (i.e., the power to try minor criminal offenses) has no power to try a murder indictment; its judgment would be void and ineffective because it lacks subject matter jurisdiction (Black 1979).

Another way of classifying jurisdiction is by the type of court, trial or appellate, hearing a case. Trial courts are usually the first to hear a case and, therefore, have original jurisdiction—authority to try a case and to determine the facts about an issue and apply the law to those facts. Appellate courts, on the other hand, generally hear and decide appeals from lower trial courts. They, therefore, have appellate jurisdiction, which gives these courts the authority to determine whether the trial court followed the correct legal procedure. Rather than trying a case or hearing the introduction of evidence, they review the trial court record (a written account of court proceedings) and the law (Rosenbauer 1978). If they find that a trial court erred, appellate courts may order a new trial or reverse the trial court's verdict without a new trial.

"Some courts have both original and appellate jurisdiction; the very lowest courts in the judicial system have original jurisdiction only, while the rest have original on some matters and appellate on others" (Bahme 1976).

APPENDIX V
THE CIVIL PROCESS

Major steps in the process are depicted in figure 5. The numbers appearing in the left margin of the figure correspond to the numbered steps on the following pages.

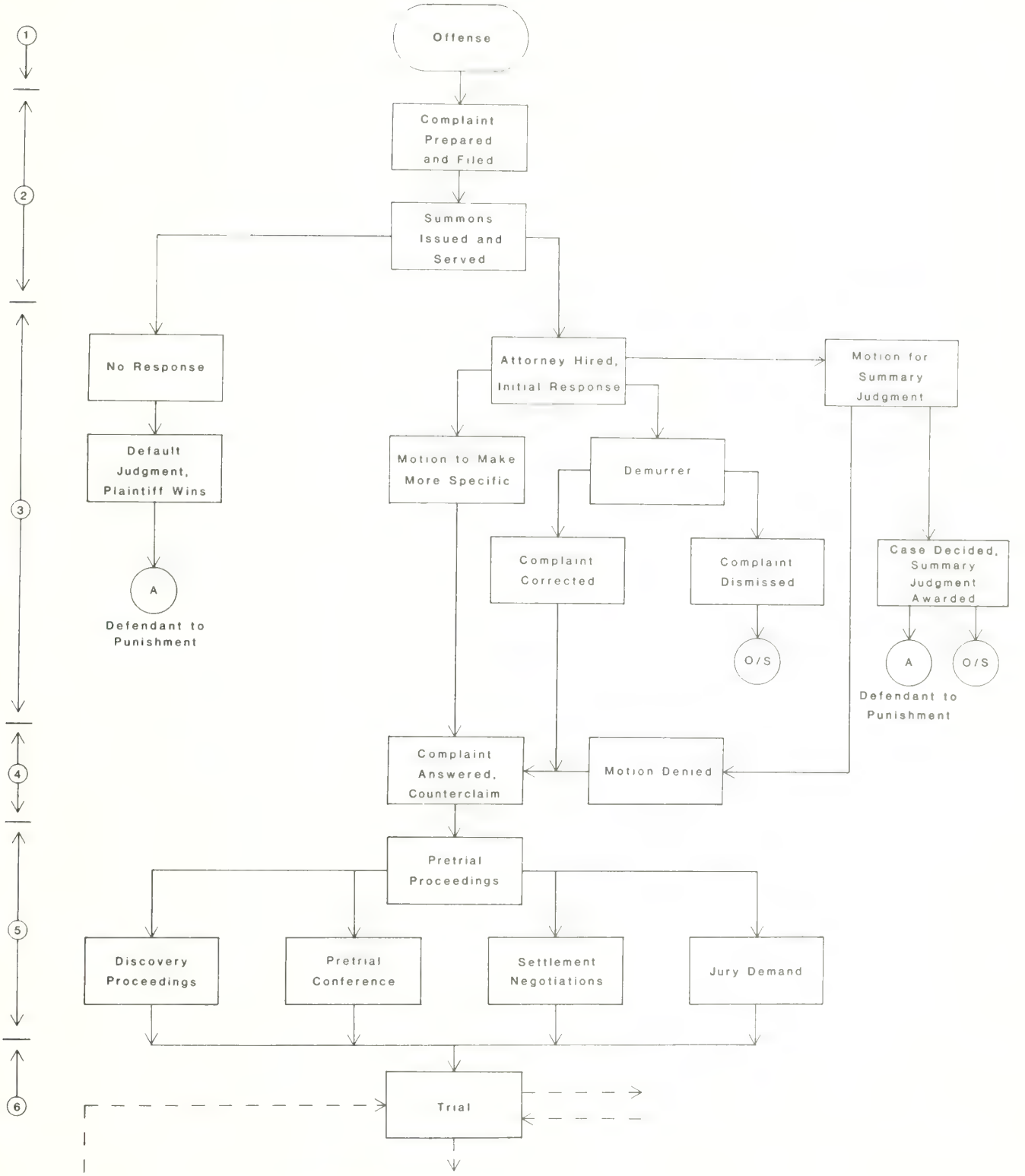
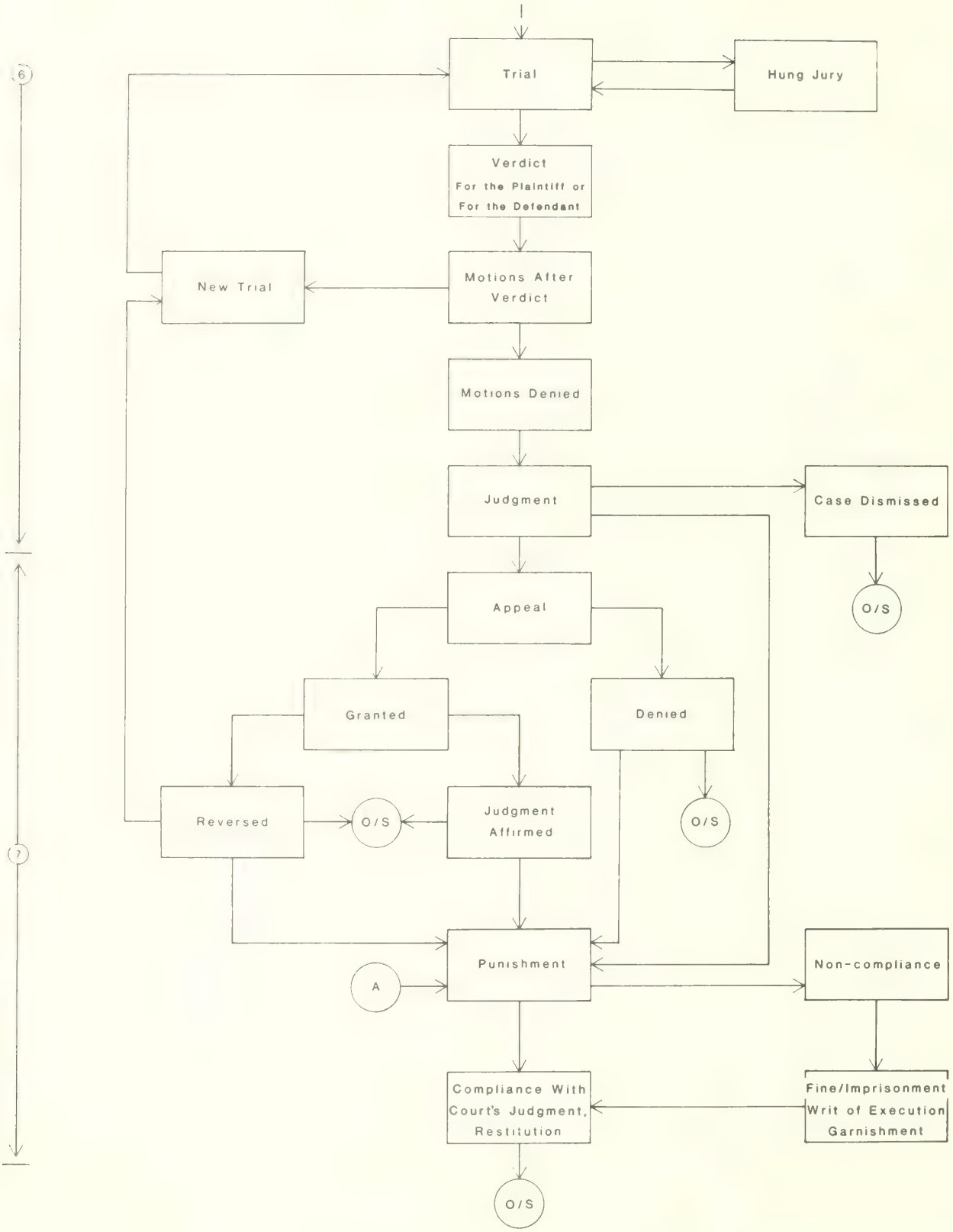


Figure 5.—*A summary of major steps in the civil process. The numbers in the left margin correspond to the numbered steps in the civil process outlined in Appendix V.*

Figure 5, continued



1. *Offense (breach of contract or tort)*

After a civil wrong has been committed, the "injured" person will generally search for, hire, and meet with an attorney. The attorney investigates and collects facts pertaining to the offense, decides on an appropriate remedy, conducts settlement negotiations with insurance companies or the other party's attorney, and decides to take the case to trial if an adequate settlement cannot be reached. If, however, the statute of limitations for the offense has been exceeded, the "injured" person can no longer seek a remedy in court.

2. *Filing a Lawsuit*

- Complaint prepared. The attorney prepares a complaint that initiates the lawsuit. It names the plaintiff and the defendant, states the alleged facts concerning the offense (allegations), and requests a prayer for damages and/or other relief.
- Complaint filed. The complaint is given to a clerk of the court (with appropriate jurisdiction) along with fees to cover court costs.
- Summons issued and served. The clerk issues a summons, attaches a copy of the complaint to it, and gives the papers to a sheriff, marshal, or professional process server who serves the papers on the defendant. A summons is a document that names the plaintiff and defendant in a lawsuit to be tried in a particular court. It directs the defendant to appear at the court within a certain period of time and states the penalty for failing to do so. Briefly, a summons alerts the defendant that a lawsuit is being undertaken against him or her.

3. *Defendant's Initial Response*

- Failure to respond to the summons results in a default judgment. The plaintiff wins the case without going to trial.
- As a rule, as soon as the summons is served, the defendant hires an attorney or is defended by his or her insurance carrier's attorneys. Initial responses to the complaint include a:

Motion to Make More Specific. If the defendant thinks the complaint is simply not definite enough, he or she may ask the judge to order the plaintiff to file a bill of particulars, which would supply additional information, within a certain number of days. A bill of particulars may also be requested in subsequent pretrial proceedings.

Demurrer. A demurrer is an application to the court to test the legal strength of the complaint and, if the complaint is found wanting, to order it corrected or dismissed. A demurrer may allege that the lawsuit was brought in the wrong court, that the summons was improperly served, or that the plaintiff failed to state a claim (cause of action).

Motion for Summary Judgment.

> If either side feels that the facts in support of its case are beyond dispute, it can attempt to save the time and expense of a trial by asking the judge to settle the matter on the basis of affidavits. He will study affidavits presented by both sides, and if he agrees that there is no argument about the facts he is free to decide the case then and there, awarding a summary judgment to one side or the other (Dolan 1972).

A summary judgment can also be made during subsequent pretrial proceedings.

4. *Answer to the Lawsuit and Counterclaims*

Assuming that the case was neither dismissed nor a judgment made, the defendant goes on to answer the lawsuit. An answer is a formal, written statement by the defendant in response to the plaintiff's complaint. In it the defendant sets forth the grounds of his or her defense, i.e., the defendant admits facts that are not in dispute, denies facts that are in dispute, and sets forth defenses such as contributory negligence. The defendant may also file a counterclaim, a claim against the plaintiff, who will respond just as the defendant responded to the plaintiff's claim.

5. *Pretrial Proceedings*

Once the complaint and answer have been filed or change hands, the case is said to be "at issue" or to have "matured" and is placed on the court calendar or docket (a list of cases waiting to be tried). At this point the following pretrial activities may occur:

- Discovery proceedings (also called disclosure proceedings or examinations before trial). Their purposes are to help attorneys for both sides prepare for trial (get facts), diminish surprise at the trial, preserve testimony and other evidence, assist in settlement negotiations that could eliminate the trial, and save time during the trial. Types of discovery include requests for admissions of fact, interrogatories, inspections of books, records, buildings, machines, etc., physical and mental examinations, and depositions.
- Pretrial conference. A conference is usually held in the judge's chambers (with only the judge and

attorneys present) or in open court (with judge, attorneys, and opposing parties present) in order to decide what issues or facts they agree on; define the issues at stake and narrow them to those essential for the successful trying of the case; agree to do away with the need for formally proving certain matters about which there is no dispute, e.g., hospital bills, lost wages, etc.; determine the possible legal questions that could arise during the trial; estimate the length of the trial, and find a common ground for settlement out of court.

- Settlement negotiations between attorneys representing the parties. These negotiations could occur at any time throughout the preparation for trial, during the trial, after the jury (if demanded) returns the verdict and before an appeal is taken, and during the pendency of an appeal.

- Jury demand. Plaintiff or defendant may file a request for a jury trial. In civil cases, a trial will generally be conducted without a jury unless it is demanded.

6. *The Trial*

If a jury has been demanded, we assume that it has already been selected and is seated in the courtroom. (If a trial is heard by a judge only, similar procedures are followed in the courtroom as with a jury. However, the attorneys would not need to make opening and closing statements. After hearing all the evidence, the judge would take the case "under advisement" and then render a judgment called a "decision.")

- Opening Statements. The attorneys for the plaintiff and defendant outline the facts they expect to prove and make clear what they are asking the court and jury to do for their respective clients. The attorneys' statements are not evidence in the case. The plaintiff's attorney speaks first, and the defendant's lawyer either follows immediately thereafter or waits until his or her portion of the case begins.

- Plaintiff's Case.

> Just as the plaintiff's side is the first to present its opening statement, so is it first to present its case. From here on evidence will play the central role in the trial. Evidence is all the factual material that each side will present to prove its case and disprove the opposition's (Dolan 1972).

The plaintiff's attorney will try to prove that the defendant is liable and that the plaintiff is entitled to a certain amount of damages and/or to other relief such as specific performance or an injunction. The primary methods for offering evidence are through questioning of subpoenaed witnesses, who can help establish the facts, and through the use of pertinent documents and exhibits brought by witnesses (via a subpoena *duces tecum*). Before witnesses are questioned, they must swear or affirm to tell the truth. When the plaintiff's attorney is finished examining each of his or her witnesses (called direct examination), the defendant's attorney has the right to cross-examine. The purpose for cross-examination is to test the witness's testimony and credibility by challenging facts given on direct examination or by eliciting other facts that might be damaging. The defendant's attorney will attempt to discredit or cast doubt on the witness's testimony so that it will lose its probative value (relative weight of the particular evidence) before the jury.

After both direct and cross-examination of the plaintiff's witnesses (and optional re-direct examination and re-cross examination), the plaintiff will rest his or her case.

- Defendant's Motion for a Directed Verdict. At this time the defendant's lawyer will customarily make a motion for a directed verdict. By doing so, he or she is arguing that the complaint should be dismissed on the grounds that, even if all the evidence presented by the plaintiff is true, the plaintiff has not proven that he or she has a cause of action. If the judge grants the motion of the defendant, the complaint will be dismissed and the case is over (but the plaintiff could take an appeal to the appellate court). If the judge denies the motion, the case will continue and the defendant will be required to answer the evidence of the plaintiff.

- Defendant's Case. The defendant's attorney will try to present evidence that would tend to show that the defendant is not liable to the plaintiff, to prove that the defendant has a defense that would excuse him or her from liability, and/or to present evidence that would justify reduction in the amount of damages sought by the plaintiff. The court swears in the defendant's first witness, who is examined first by the defendant's attorney and then is cross-examined by the plaintiff's attorney, and so on. "When the defendant's witnesses have finished, the plaintiff can recall some of his witnesses, or call some new ones, to give 'rebuttal' evidence—evidence to disprove some of the things the defendant's witnesses have said" (Eichner 1963).

- Motions for Directed Verdict. When all of the evidence has been presented, either one or both parties may make a motion for a directed verdict. Basically, this means that the plaintiff or defendant (or

both) thinks the evidence is so much in his or her favor that a jury could not reasonably decide in favor of the opponent. If the judge agrees and grants the motion, the trial is ended and the losing party can take an appeal to the appellate court. If the motion (or motions) is denied, the trial continues.

- Closing Statements. The attorneys for each side sum up the case for the jury from the viewpoint of their respective sides. Each attorney reviews the evidence, stressing the strong points of the case and the weaknesses of the adversary's case. The plaintiff argues first, then the defendant, and finally, the plaintiff, because he or she bears the burden of proof.
- Instructions to the Jury, Jury Deliberations, and Verdict. Before releasing the jury to consider a verdict, the judge "charges" the jury, i.e., he or she instructs the jury, beginning, for example, with a statement of the issues at stake and of the claims made by both parties.

> From there [the judge] generally moves to an explanation of the general laws that apply to civil actions, including the reminder that the plaintiff need not prove his case beyond a reasonable doubt but simply show the bulk of evidence to be in his favor. Next [the judge] turns to a rundown of the laws applicable to this particular case [and] finally ... advises the jurors on the form that their verdict should take: it should be a decision to award or not award damages, and if it is to award it should designate the amount of the award. When the judge has concluded his remarks either attorney may object to any portion of them and may ask that additional instructions be given (Dolan 1972).

The jury then leaves the courtroom in an attempt to reach a verdict. When it returns, it will come with a verdict in hand (unless it's a "hung jury") that will be "for the plaintiff" or "for the defendant."

- Motions After Verdict. After the jury's verdict, "the losing side may ask the judge to set aside the verdict on the ground that the evidence was such that the jury could not reasonably have reached the conclusion it did, or because of some serious mistake in the conduct of the trial which may have unfairly influenced the jury" (Eichner 1963). If the motion for a new trial is granted, then the case will be heard all over again at a later date. If the motion is denied, the court enters a judgment.
- Judgment. Once the judgment (the final decision of the court resolving the dispute and determining the rights and obligations of the parties) has been made, the civil case is ended at the trial level.

7. *Posttrial Activities*

Following the judgment, several things can happen:

- The losing party (defendant or plaintiff) can make an appeal to a higher court. When the trial court decides for the plaintiff and the defendant appeals, the defendant faces punishment determined by the trial court if the appeal is denied. If the plaintiff appeals after the trial court decides for the defendant and the appeal is denied, the case is dismissed.

An appeal is initiated by filing a claim of appeal with the clerk of the trial court that rendered the judgment. The clerk prepares a record that is forwarded to the appropriate appellate court. The record contains the trial pleadings (complaint, answer, etc.), transcripts of the testimony, exhibits, and instructions to the jury. In addition, the appellant (unsuccessful party) prepares a brief, filed with the appellate court, that includes the issues, a concise statement of the facts, and a legal argument wherein he or she cites the laws and cases to support his or her position. The appellant's brief is served on the appellee (successful party), who also prepares a brief and files it with the appellate court. It, in turn, is served on the appellant, who prepares a reply brief. Assuming that the appeal is granted, the appellate court usually hears an oral argument from the attorneys representing the opposing parties. No testimony is taken in the appellate court; instead, it decides the case on the basis of the record transmitted to it by the clerk of the lower court, the briefs, and the attorneys' oral arguments. The appellate court then writes an opinion setting forth the facts, issues, law(s), and applications of the law(s) to facts. Based on its opinion, the court will either reverse or affirm the trial court's judgment. If the judgment is reversed, the court will either enter a final judgment (resulting in punishment for the appellant or dismissal for the appellant) or remand (send back) the case to the trial court for a new trial or for some other further proceeding (Eichner 1963). If the appeals court affirms the trial court's judgment for the plaintiff, the defendant (appellant) must pay damages or otherwise remedy the offense. If, on the other hand, it affirms a trial court's judgment for the defendant, the plaintiff's (appellant) case ends (unless there's still a higher court to which the losing party can appeal).

- If the plaintiff wins and the defendant pays the damages or otherwise remedies the situation, then the plaintiff's case is vindicated and both parties are out of the legal system.
- Likewise, if the defendant wins (and therefore is vindicated) and the plaintiff is satisfied with that decision, then both plaintiff and defendant are no longer in the legal system.
- If the defendant does not comply with the court's judgment, the court can take action to force compliance. Individuals violating injunction orders, for example, can be held in civil contempt, resulting in fines or imprisonment, until they comply with the orders. Similarly, if the defendant does not voluntarily pay damages specified in the judgment, the court can issue a writ of execution to enforce the judgment. The writ directs a law enforcement officer, such as a sheriff, to seize and sell certain property of the defendant not exempt by statute. The proceeds are used to pay the judgment. If the defendant has no property or has insufficient property to satisfy the judgment, those who owe the defendant money may be served with a garnishment process whereby the court directs them to pay the money to the plaintiff rather than the defendant. Once restitution has been made, the civil process is completed.

APPENDIX VI
THE CRIMINAL PROCESS

Major steps in the process are depicted in figure 6. The numbers appearing in the left margin of the figure correspond to the numbered steps below.

Input

1. *Detecting and Reporting a Criminal Offense*

"Input [into the criminal process]occurs when a crime is committed and its commission is somehow [detected and] made known" (Chamelin *et al.* 1975). Crimes can be detected and reported in a number of ways. For example, a "crime may be observed by a private citizen who reports it ... to the police; a police officer may observe the commission of a crime; [or] a grand jury may discover the commission of the crime upon an investigation undertaken of its own initiative" (Chamelin *et al.* 1975).

2. *Identifying the Offender*

This second and obvious stage of input may require little effort (e.g., when a crime is committed in the presence of a police officer) or it may take days, weeks, months, or years. But without it, the criminal process cannot commence (Chamelin *et al.* 1975). (In addition, if the statute of limitations for the crime has been exceeded, the process may not be invoked.)

Pretrial Process

3. *Investigation and/or Arrest, Court Summons, Citation, or Violation Notice*

An "arrest may or may not be the first step in the pretrial process. ... [This depends on] the method by which the existence of a crime and the identification of an offender is made known" (Chamelin *et al.* 1975). If a felony or misdemeanor is committed in the presence of an officer (or private citizen) or if an officer has probable cause to believe a person has committed a crime, he or she may arrest the suspected law violator immediately without a warrant.

An arrest may be preceded, however, by a grand jury or law enforcement officer investigation. The investigation can include "the search and recording of the crime scene, the collection and preservation of evidence, ... the uncovering of all sources of information, the surveillance of suspects, their interview and interrogation, [and] the interview of witnesses and victims" (Germann *et al.* 1977).

After an investigation (which may continue throughout the pretrial process) the case will either be dropped because of insufficient evidence or an arrest warrant may be issued. "Arrest with a warrant may be used for all types of offenses—felonies and misdemeanors. Such an arrest normally follows the filing of a complaint by the prosecuting attorney alleging the commission of a crime" (Berkley *et al.* 1976). The complaint is filed with a U.S. Magistrate (in a Federal matter) or a State trial court judge. "If a magistrate is convinced that the crime alleged in the complaint has been committed by the accused, he may issue a warrant of arrest" (Berkley *et al.* 1976). An arrest, with or without a warrant, does not prove someone is guilty and is not a punishment. Its purpose is to ensure the presence of an accused person to answer charges before a court of law.

For minor criminal offenses, a summons, citation, or violation notice is often issued in lieu of arrest, thus avoiding taking a suspect into immediate physical custody. "A summons is a written document that notifies an individual that he has been charged with an offense and orders him to appear in court at a certain time and date to answer the charge" (Chamelin *et al.* 1975). If a

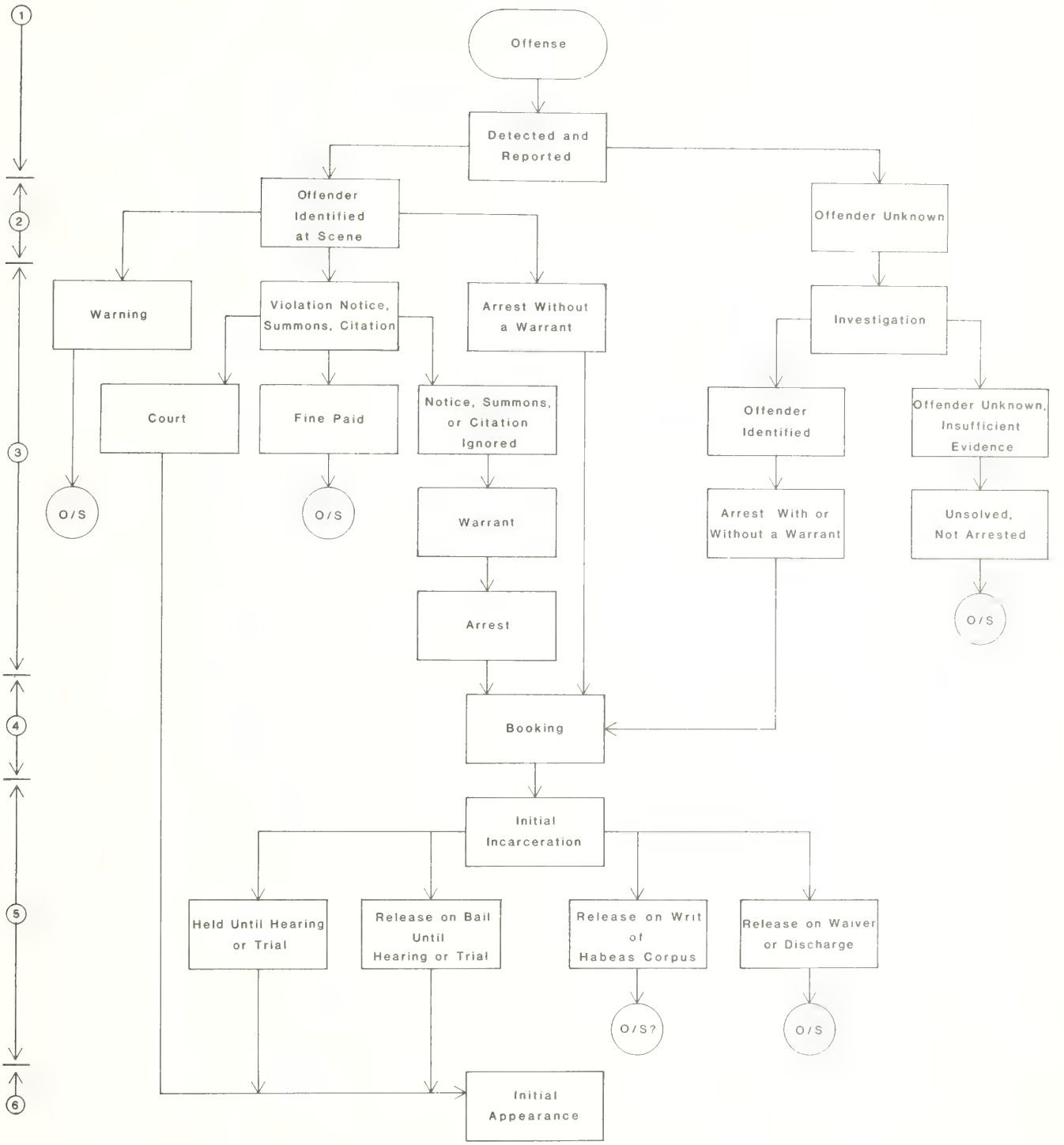


Figure 6.—*A summary of major steps in the criminal process. The numbers in the left margin correspond to the numbered steps in the criminal process outlined in Appendix VI.*

Figure 6, continued

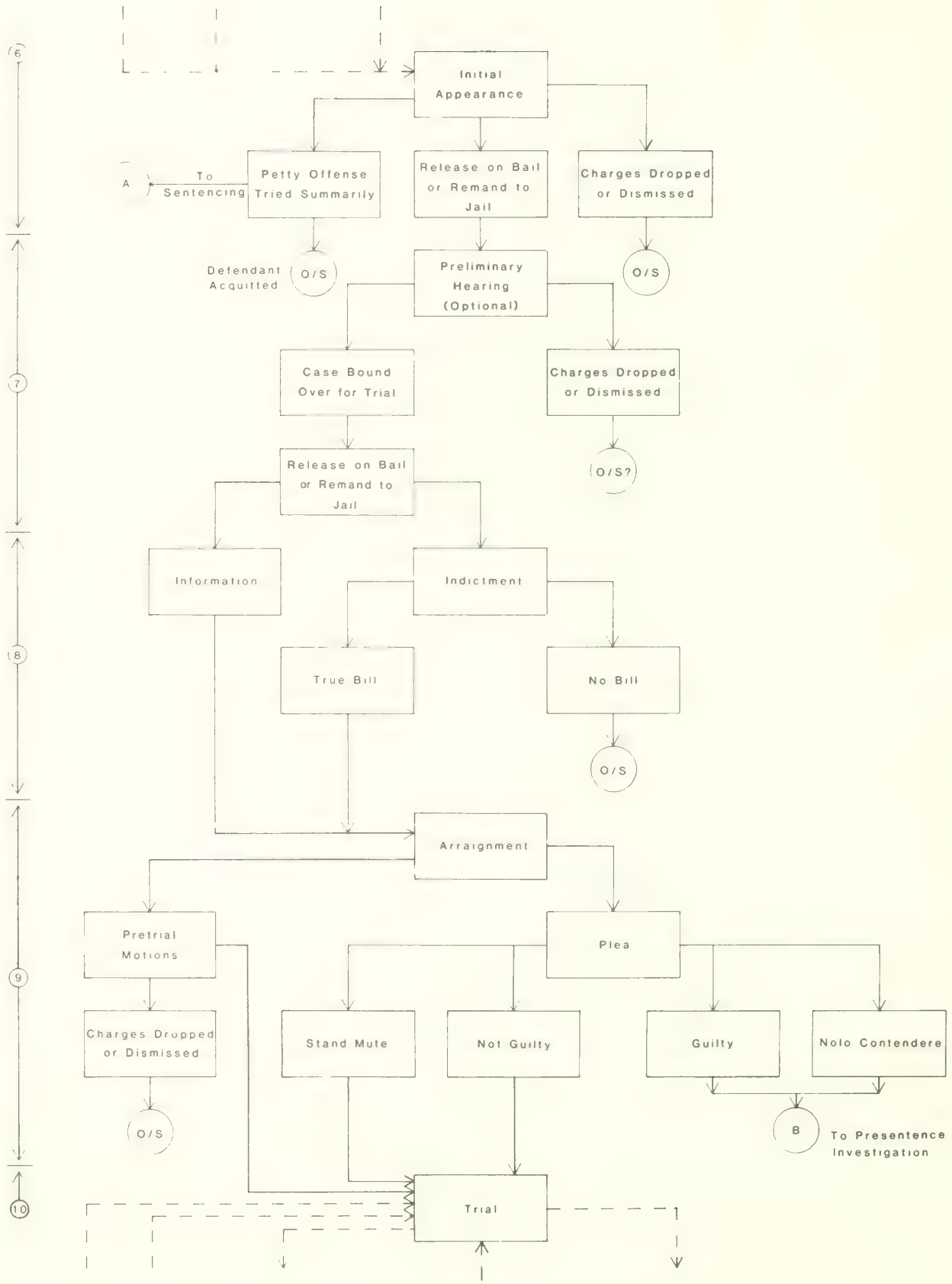


Figure 6, continued

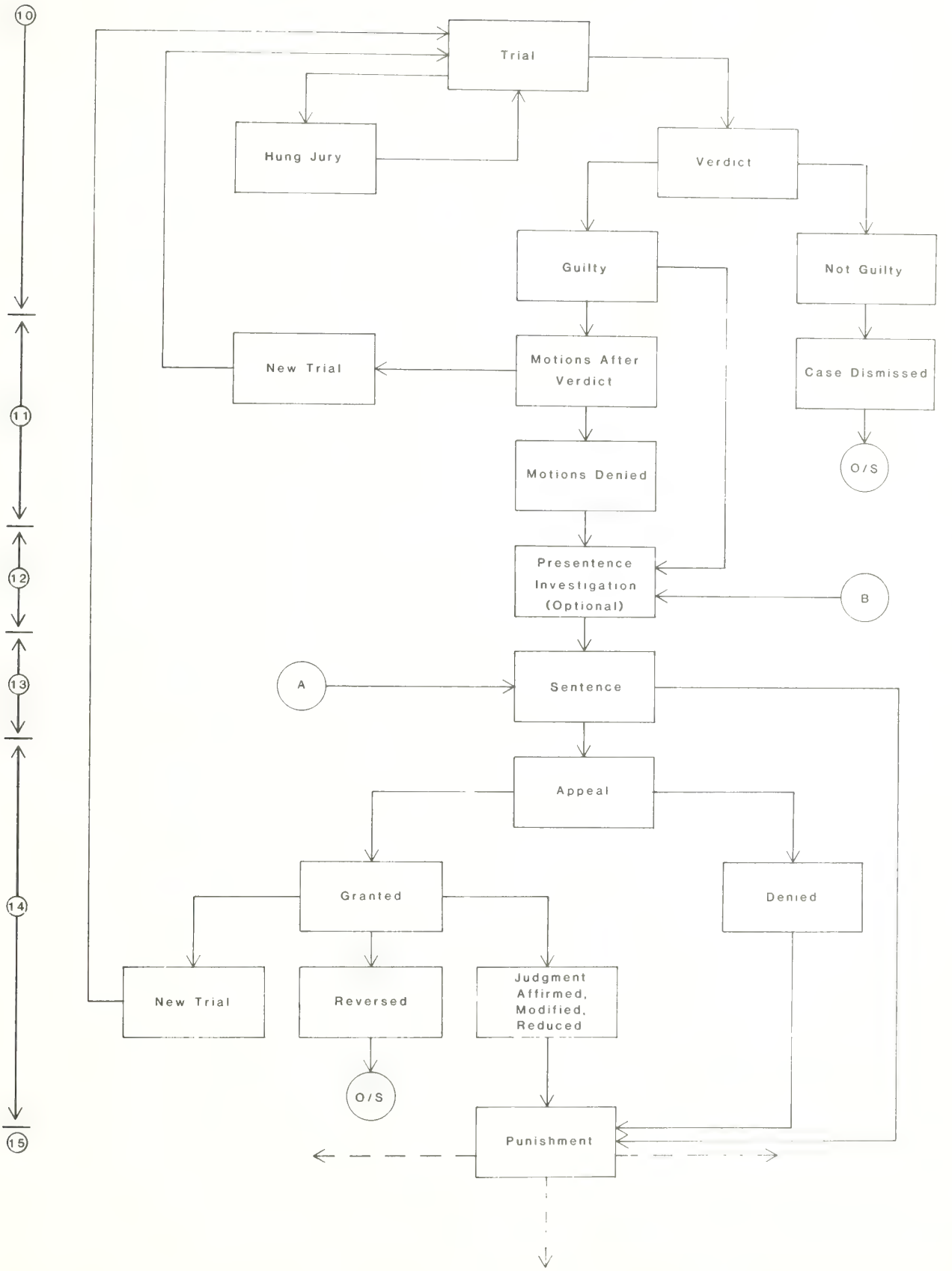
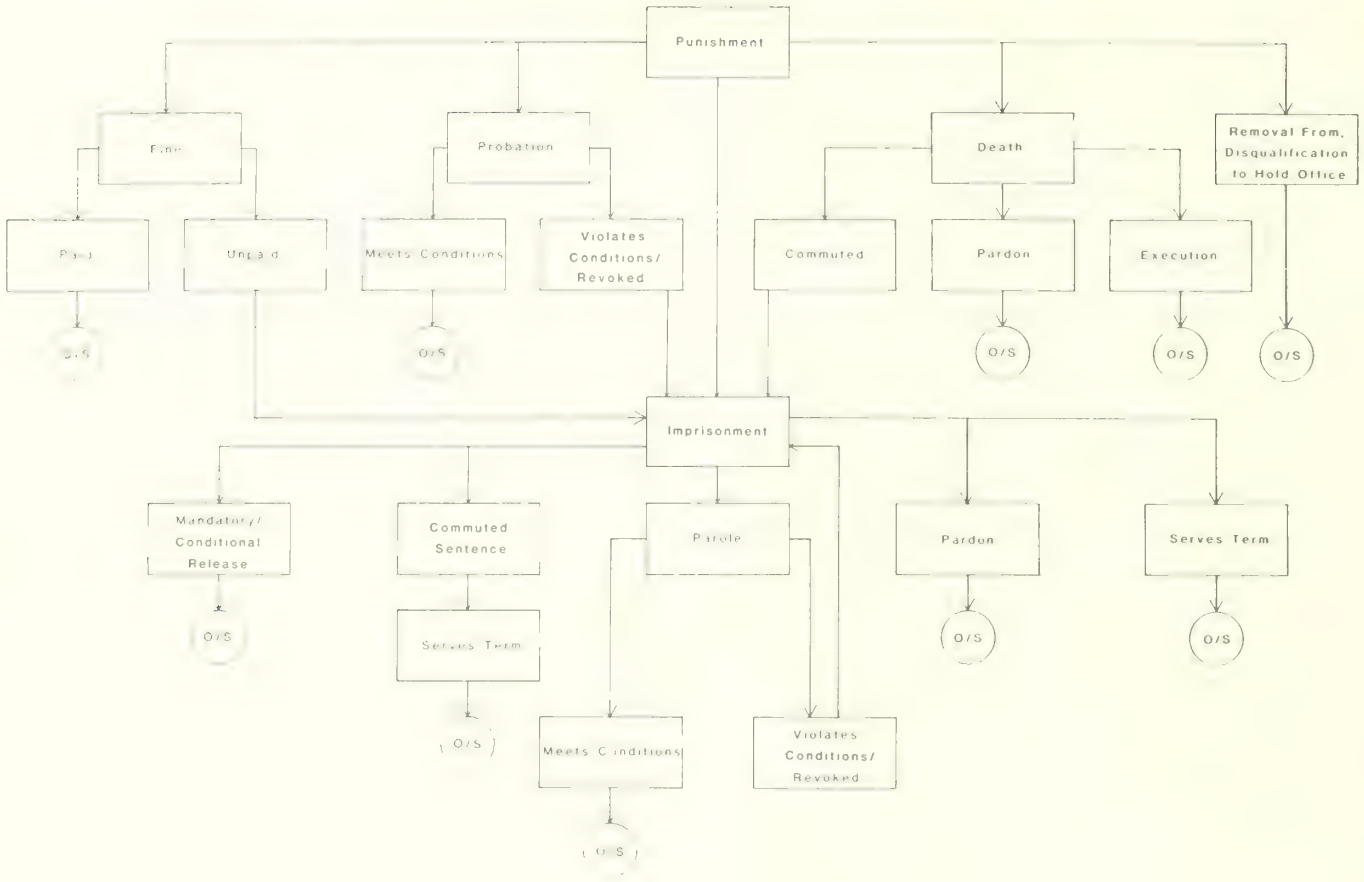


Figure 6, continued



summons is ignored, a warrant is issued for the offender's immediate arrest. A citation or violation notice is used most often for petty offense misdemeanors such as minor traffic violations and operates in the same manner as a court summons. It describes the nature and location of the offense and commands the suspect to pay a fine or to appear before a certain court on a specified day. If a citation or violation notice is ignored, a court summons or arrest warrant can be issued. When authorized, a verbal or written warning can be issued instead of a violation notice if an offense was due to inadvertence, misunderstanding, or misinformation.

4. *Booking*

Booking is an administrative record of arrest. It involves entering the date, the time, the suspect's name and address, the specific charge against him or her, and other relevant facts on the police "blotter"; photographing and fingerprinting the suspect; and inventorying the suspect's personal belongings.

5. *Initial Incarceration*

After booking, a suspected law violator is formally detained in a city or county jail, pending a hearing. If the prisoner remains in custody, he or she must appear before a judicial officer—generally a judge or magistrate (sometimes called a committing magistrate)—as soon as possible. He or she can be released from custody, however, by posting bail,[37] by a writ of *habeas corpus*, or by a waiver or discharge. A writ of *habeas corpus* is an order from the court "commanding that the person detaining another produce the prisoner" (Germann *et al.* 1977). If the court decides that there is insufficient cause for detaining the prisoner, the suspect

[37] *Bail may consist of either a cash deposit left with the court by the individual or security put up by a licensed bonding company (or others) that will guarantee the individual's appearance in court at the required time. According to Berkley* et al. *(1976), bail may be specified on the arrest warrant or on a schedule provided to the police by a magistrate; "This is most frequently the case for misdemeanors. By posting the amount specified on the warrant or the schedule, the defendant may gain release prior to the initial appearance." Bail may be set after booking and before the initial appearance, before or after the preliminary examination, the arraignment, the trial, the sentence, or pending an appeal (Germann* et al. *1977).*

will be released. A person may be given a waiver or discharge if a prosecutor refuses to issue a formal accusation due to insufficient evidence or if the person's innocence becomes obvious after investigation.

6. *Initial Appearance*

The initial appearance of a suspect before a judge or magistrate may serve one or more functions depending on local procedure and the seriousness of the offense. The primary purposes are to inform the suspect of the charge(s) against him or her and to advise the person of his or her constitutional rights. Bail may also be set during the initial appearance.

In addition, petty offense (low) misdemeanors can be tried summarily at this point by a judge (without a jury) having trial jurisdiction. After receiving the formal notice of charge and advice of rights, the defendant will be asked to plead to the charge. If the plea is guilty or *nolo contendere* (no contest), the judge may sentence the defendant immediately. Likewise, if the plea is not guilty and the complaining witness is available when the plea is entered (or in the case of high misdemeanors, the defendant waives a trial by jury), the judge may try the case without further delay. The initial appearance is the only step in the criminal process in which cases can be disposed of in this manner (Berkley *et al.* 1976).

7. *Preliminary Hearing*

Following the initial appearance by the accused, a preliminary hearing, although optional, is usually held before a judge or committing magistrate.[38] The judge decides, in light of the evidence presented by the prosecutor, whether or not the crime charged did occur and whether or not it's reasonable to believe that the accused may have committed it (Germann *et al.* 1977). If sufficient probable cause has been shown, the judge will bind the case over to the appropriate court for trial (and, depending on the situation, set bail or remand the defendant to jail) (Chamelin *et al.* 1975). If probable cause has not been established, the case against the defendant is dismissed, at least temporarily, for lack of evidence. (After dismissal, the prosecutor can file an information against the accused or a grand jury may return an indictment.) One of the primary functions of the preliminary hearing, therefore, is to limit unwarranted prosecutions. During the preliminary hearing, which is not a trial to determine guilt or innocence, charges against the defendant may also be reduced.

8. *Information or Indictment*

After the preliminary hearing, the prosecutor (or district attorney) will prepare an information for the trial court. An information is a written accusation against a person for some criminal offense (a felony or a misdemeanor), without an indictment (Black 1979). Although it resembles in form and substance an indictment, it differs in that it is presented by a public prosecutor instead of a grand jury.

An alternative to the filing of an information is the filing of a grand jury indictment. An indictment is a "formal, written accusation originating with a prosecutor [but] issued by a grand jury against a [person] charged with a crime" (usually a felony) (Black 1979). "Like the preliminary hearing, the grand jury is designed to protect the defendant from unwarranted prosecutions. Unlike the preliminary hearing, however, the proceedings ... are in secret, and the prosecution simply places its case before the jury" (Berkley *et al.* 1976). The grand jury "functions similarly to the committing magistrate by examining facts surrounding a crime and determining if probable cause exists to order an accused held for trial .... If the jury decides there is sufficient evidence, it issues a 'true bill' [of indictment]. If it finds the allegations are unwarranted, it hands down a 'no bill'" (Chamelin *et al.* 1975).[39] The U.S. Constitution requires that a

[38] *Although a defendant can waive a preliminary hearing because he or she intends to plead guilty or has little hope of gaining a dismissal, most defense attorneys recommend against a waiver. The preliminary hearing not only presents an opportunity for dismissal from the criminal process but it also serves as a tool of discovery for the defense. Although the prosecutor must present enough of his or her evidence to establish probable cause, the defense may cross-examine but need not present evidence or witnesses.*

[39] *In addition to their function as an accusatory body, grand juries can investigate, at the request of another official or private citizen, matters of public interest or other possible criminal infractions (Chamelin* et al. *1975). Then, if appropriate, grand juries may seek criminal charges against suspected law violators. They do not always have to wait for a prosecuting attorney to initiate the proceedings. As a result, a grand jury may, in some cases, initiate the criminal process; an indictment can be returned before a defendant has been taken into custody and a bench warrant subsequently issued for his or her arrest.*

grand jury be used for all Federal felony cases; many States also require grand juries for felonies (and in some cases, high misdemeanors). But, if a defendant waives indictment by a grand jury, prosecutions of all but capital offenses can begin by filing an information. "Waivers are frequent and most prosecutions of even serious [crimes] in [State and Federal] courts are by information" (Gibney, ed. 1979).

9. *Arraignment*

The arraignment is a procedure in which the defendant is brought before a judge of a trial court[40] to plead to the criminal charge in the indictment or information (Black 1979). The charge is read to him or her and the defendant is asked to enter a plea. The defendant may stand mute (say nothing) or plead one of three ways—not guilty, guilty, or *nolo contendere*. If the defendant stands mute (the court automatically enters a plea of not guilty for the accused) or pleads *not guilty*, the judge will set a trial date. If a criminal trial is required, the defendant can choose at the arraignment whether to be tried by a judge or by a jury.

The defendant may plead *guilty* as charged or to a lesser offense (often resulting from plea bargaining). If the guilty plea is accepted, the judge will set the date and time for sentencing. But, if the court refuses to accept a guilty plea, it will enter a plea of not guilty. If the plea is *nolo contendere*, it is treated as a guilty plea although it is not an admission of guilt but a willingness of the accused to accept conviction and not go to trial. If civil action against the defendant is likely, he or she can, by pleading *nolo contendere*, avoid having the guilty plea to the criminal offense become a part of the trial for the civil offense (Germann *et al.* 1977).

During the arraignment, pretrial motions "are usually made by the defense attorney for the purpose of doing all in his power to have the charges dismissed, have evidence possessed by the state declared inadmissable, or find out as much as he can about the state's case in order that he may better prepare his defense" (Chamelin *et al.* 1975). These motions may include, for example, a motion to suppress evidence (the defense attempts to show that some evidence was obtained illegally) or a motion for dismissal due to lack of evidence. If the defense feels that a fair trial is unlikely in the area where the crime was committed, he or she may also make a motion for change of venue.

[40] *"In the federal system, the arraignment is usually before a U.S. district judge although U.S. magistrates can and have presided over arraignments" (Berkley* et al. *1976).*

Pretrial motions serve two other purposes. They can be used to delay the trial, giving the defense additional time, but, more importantly, to answer many legal questions, allowing the judge to decide on matters before the trial rather than during the trial, resulting in a savings of time and money (Chamelin *et al.* 1975).

Trial Process

10. *Trial*

Once it starts, a criminal jury trial is very similar to a civil trial (Appendix V). We assume the jury has been selected and is seated in the courtroom.

- Opening Statements by the Prosecution and Defense. The purpose of the prosecutor's opening statements is to "set the stage," to explain the general facts of the case, the issue or issues to be tried, and what is going to be proved to the jury. If the defense chooses to make opening remarks (it can reserve its statements until the state [prosecutor] has presented its case), the counselor will reveal how he or she plans to show the weaknesses in the state's case and convince the jury of the defendant's innocence.

- Prosecutor's (or state's) Case. The prosecutor calls witnesses and presents evidence to show that a crime was committed and that the defendant committed it (Chamelin *et al.* 1975). Witnesses, including members of law enforcement agencies, will present evidence for the state under sworn testimony. After the prosecutor examines each witness and is satisfied that the witness has supplied the necessary information, the defense attorney is given the opportunity to cross-examine the witness—to "impeach" or destroy the credibility of the witness and/or his or her testimony in the minds of the jurors. The cycle of direct examination and cross-examination continues with each witness until the state has presented all of its evidence (Berkley *et al.* 1976). When the state feels that it has done as much as possible in meeting the proof required in the particular crime and in showing the defendant's guilt, it rests its case.

- Motion for Dismissal or Directed Verdict. At the close of the prosecutor's case, the defense usually asks for the dismissal of the case or for a directed verdict of innocence or acquittal. These motions may be made on the grounds that the prosecutor failed to show, for example, that a crime was committed, that the defendant committed the crime, or that the defendant's guilt has been shown beyond a reasonable doubt (Chamelin *et al.* 1975). If the

motion is granted, the case is dismissed and the defendant freed. If the motion is denied, however, the defense must present its case to the jury.

- Defense's Case. "The pattern of presentation of the defendant's case is the same as that for the state. The roles are simply changed" (Berkley *et al.* 1976). The defense attorney directly examines his or her witnesses and then offers them to the prosecutor for cross-examination. "The defense is not required to prove innocence of the defendant but rather to show that the state has not or cannot prove his guilt" (Chamelin *et al.* 1975). The defense rests its case when all the witnesses have testified and all the evidence has been presented.

- Rebuttal and Surrebuttal. After the defense rests its case, the prosecutor may call rebuttal witnesses to refute the testimony of the defense witnesses and bolster the state's case if it has been weakened by the defense. The defense may, in turn, engage in surrebuttal by bringing forth additional witnesses to challenge points raised by the state's witnesses.

- Motion for Dismissal or Directed Verdict. If the defense counsel did not move for dismissal earlier, this motion usually will be made after the defense surrebuttal. If the motion is denied, both sides will make their summations or closing statements.

- Closing Statements. Both the prosecuting and defense attorneys attempt to review the law and facts for the judge and jury and to summarize the important facets of the case (Germann *et al.* 1977). The prosecutor will emphasize the strong points of evidence against the defendant, and the defense will point out the weaknesses in the prosecutor's case and emphasize that the burden of proof is on the state (Berkley *et al.* 1976).

- Instructions to the Jury, Jury Deliberations, and Verdict. Before releasing the jury to consider a verdict, the judge instructs or "charges" the jury, i.e., he or she sums up the case and tells the jury about the rules of law that should be applied to the facts of the case. The judge may, for example, talk about the meaning of "burden of proof" and "presumption of innocence" and discuss the procedures the jury should use in reaching a verdict.

After receiving the judge's instructions, the jury retires to the jury room to begin secretly discussing and voting on its verdict. When a verdict is reached, the judge reconvenes the court and the jury is brought in to announce its verdict. If the verdict is not guilty, the case is dismissed and the defendant is freed. If the verdict is guilty,[41] a date is set for sentencing and the judge usually requests a presentence investigation.

Posttrial Process

11. *Motions After Verdict*

Before sentencing, a motion for a directed verdict (requesting the judge to reverse the jury's decision or substitute his or her judgment for the jury's) or a motion for a new trial is generally in order. The defense will most often move for a new trial on a number of grounds ranging from misconduct of the jury to errors of the judge. "If a mistrial is declared or a new trial is granted, the accused will be placed on bail or remanded to custody until the time of the new trial" (Germann *et al.* 1977).

12. *Presentence Investigation*

If the defendant does not win a new trial, then a presentence investigation usually occurs. Generally, a probation or parole officer investigates the background of the proven law violator—the family history, former criminal convictions, education, work performance, etc.—and submits a report with recommendations for the sentence and treatment programs. Although a criminal statute declares an act a crime and also names maximum punishments, the judge can individualize the sentence based on the probation officer's report or even on his or her own intuition.

13. *Sentence*

When the proven law violator appears for sentencing, the judge has a variety of punishments that can be imposed depending on the crime, the presentence investigation, and statutory demands (Germann *et al.* 1977). Some of the sentences that may be given include fine, suspended sentence, probation, imprisonment, and in some States, execution.

14. *Appeal*

Following the sentence, the offender may appeal his or her conviction, but the "appeal must be based on a legal error—a misinterpretation or misapplication of the law by the trial judge" (Berkley *et al.* 1976). If the case was first heard in a minor court, the next court will hear it *de novo* (as new), because many courts do not keep a record of the proceedings. If the case was heard from a court of general jurisdiction, however,

[41] *"In trials before a judge, two verdicts are possible, guilty or not guilty. When the trial is before a jury, the possibility of a 'hung' jury is added. The defendant is usually retried when a hung jury occurs. In some circumstances, however, the judge may dismiss the case" (Berkley* et al. *1976).*

(e.g., a circuit court), the case for appeal is made on the transcript (record) of the first court and is heard in an appellate court. "The appellate court may *affirm* the finding of the lower court; may *modify* or *reduce* the degree of offense or punishment imposed; may *reverse* the finding of the lower court; may *set aside*, *affirm*, or *modify* proceedings around judgment; or may authorize a *new trial*" (Germann *et al.* 1977).

15. *Punishment (Corrections) and Release*

If the appellant (the defendant) does not win an appeal, he or she must satisfy the terms of the sentence given after conviction (e.g., fine, probation, imprisonment, death, or removal from or disqualification to hold office). Once proven law violators have paid fines or have been released on suspended sentences, they go back into society as free persons. (If fines are not paid, the offender may be incarcerated.) If given probation, an alternative to a jail or prison sentence, they receive out-of-jail supervision by an officer of the court. "Specific conditions [are] imposed on the probationer.... A violation of one or more of the conditions [e.g., keeping regular hours, maintaining gainful employment, avoiding public drunkenness] could result in the revocation of probation and imprisonment of the offender" (Berkley *et al.* 1976).

If sentenced to jail or prison terms, offenders have a chance for rehabilitation, counseling, and perhaps an education. If approved by a State parole board or the U.S. Parole Board, offenders may be placed on parole. Parole is "a conditional release of a prisoner, generally under the supervision of a parole officer, who has served part of the term for which he was sentenced" (Black 1979). If a parollee violates the rules of parole, he or she may be reprimanded, penalized by more rigid rules, or sent back to jail or prison to serve the rest of the sentence.

Other releases from incarceration include mandatory/conditional release, a commuted sentence, a pardon, or an expired sentence (serves term). Mandatory or conditional releases, provided by several States, free all or designated prisoners 6 months or more before their sentences expire. They allow prisoners to adjust, under supervised conditions, to life outside prison walls. A commuted sentence is an executive reduction or change in punishment to one which is less severe, e.g., from execution to life imprisonment. A pardon, an "act of grace" from the executive branch of government, releases the offender from the entire punishment prescribed for the offense (Black 1979). A pardon releases an incarcerated law violator directly into society as does an expired sentence.

> Two-thirds of *all* releases are by expiration of sentence.... The persons released by discharge are usually those who are the most difficult to rehabilitate and have therefore been denied paroles. Some jurisdictions do not discharge without supervision because gradual reentry into society is most needed by the difficult offenders and society needs some protection until they are adjusted. All types of parole and other release procedures, of course, are designed to return the offender from the prison or correctional institution to the free community and keep him there (Chamelin *et al.* 1975).

APPENDIX VII
SIMILARITIES AND DIFFERENCES BETWEEN THE CIVIL AND CRIMINAL PROCESSES

Some of the major similarities and differences between the civil and criminal processes are discussed below:

- A civil case can be initiated by anyone with a complaint, including the government (e.g., as in contract defaults). A criminal case can only be initiated by the government, representing the people. Even though a crime may be directed at one person, it is considered an offense against the public.
- In a civil case, the private citizen, organization, institution, or governmental body initiating a lawsuit as "victim" is called the plaintiff. In a criminal case, the victim cannot initiate the action; the people, represented by a prosecutor, initiate the case. The complainant ("victim") may be called the complaining witness or the prosecuting witness and may be the chief source of evidence against the charged law violator. In both cases, the person charged is called the defendant.
- In civil suits, the plaintiff employs a self-chosen attorney and knows the attorney will work in his or her best interest. In criminal cases, the victim has little say about how the case will be handled. Because criminal cases are brought in the public interest and are controlled by public prosecutors, a prosecutor may dismiss an action over the objections of the victim (the complaining or prosecuting

witness) or may press for a prosecution even though the defendant and victim have settled their differences. (The victim cannot make private agreements with the defendant that would absolve the defendant of guilt.)

- In both civil and criminal cases, the defendant has a right to employ the services of a counsel of his or her own choosing. If defendants facing serious criminal charges cannot afford to employ counsel for themselves, they have a right, under the U.S. Constitution, to a court-appointed defense counsel paid for by the government. No similar right exists in civil or in minor criminal cases.

- Many civil cases are settled out of court or even before the case gets to court. Very few criminal cases are settled out of court.

- When a defendant's act leads to both civil and criminal action, theoretically, the actions are entirely separate and may even be filed in separate States. Most civil actions can be filed anywhere the defendant can be found, but criminal actions must be filed where the criminal act occurred.

  The outcome of the criminal case (which is tried first) does not ordinarily affect the outcome of the civil case, because the standards of proof required are different. However, once criminal guilt has been established, that guilt can carry weight in civil court.

- A grand jury may be convened to aid the prosecutor in investigating a suspected crime, to determine whether criminal charges should be made, and, if so, what charge and against whom. Witnesses may be compelled by a grand jury to appear, testify, and produce documents in secret sessions excluding the public. (In fact, witnesses' attorneys are not even permitted to attend.) No grand jury procedure is available to help with investigations in civil cases.

- In a civil case, the plaintiff can subpoena the defendant and force him or her to testify under oath and to produce business files and records that contain evidence damaging to the defendant. The prosecutor in a criminal case, however, cannot use the defendant's testimony unless the defendant elects to testify. Under the U.S. Constitution, no person can be compelled in a criminal case to be a witness against himself or herself.

- Rules of procedure in civil cases are different from rules of procedure in criminal cases. For example, in a civil case the defendant's answer to a charge is in writing and is filed with the court clerk, but in a criminal case the answer is given orally in open court.

- In civil cases, plaintiffs and defendants will not have a jury unless they demand one. In a criminal case, a defendant can have a jury unless he or she waives the right to a trial by jury. (Petty offense cases are the one exception; a defendant cannot have a jury.)

- Once the plaintiff/prosecutor and defendant have rested their cases and the judge has instructed the jury on the law, the jury retires to determine the verdict. In a civil case, the jury would "find for the defendant" or "find for the plaintiff," and, if the latter, might name the sum of money the defendant must pay the plaintiff to rectify the wrong.

  If the jury finds a defendant in a criminal case guilty, in some States the jury might have to determine the punishment. (Elsewhere, and in Federal courts, the judge sets the sentence.) In court, the jury will find the defendant *guilty as charged* or *not guilty.*

- In a civil case, damages are payable to the victim (except for court costs). If the defendant fails to pay, the money owed is collected by such procedures as seizure and sale of the defendant's property or by garnishment of his or her wages. Generally, defendants are not imprisoned for failure to pay damages (unless they have lied under oath about their assets, for example).

  If a defendant owes money in a criminal case, the money is payable to the state as a fine and no part of it goes to the victim. Of course, sometimes judges exert pressure on defendants to return stolen property or to compensate the victim for damaged property. If a defendant fails to pay, he or she is generally imprisoned. The enforcement of the people's rights in a criminal case is much more certain than the enforcement of the plaintiff's rights in a civil case.

- The plaintiff in a civil case wins if he or she shows that the *preponderance of evidence* is on his or her side. This means that the plaintiff must persuade the judge or jury that he or she is somewhat more likely to be right than the defendant.

  The people win a criminal case only if the defendant's guilt is established *beyond a reasonable doubt,* for the "burden of proof" rests with the state, and a person is presumed to be innocent until proven guilty in a court of law. If the defendant's attorney can show there is a "reasonable doubt" about his or her client's guilt, the defendant may be declared not guilty of the criminal charges.

- The purpose of a civil suit is to rectify a noncriminal wrong by compensating the person wronged,

usually through monetary damages. The purpose of a criminal action is to determine the innocence or guilt of a suspected wrongdoer, and if he or she is found guilty, to assign a punishment.

- In a civil case, the losing side can appeal the decision to a higher court if they feel that the suit was improperly conducted. If the defendant is found guilty in a criminal case, he or she may also appeal. If the defendant in a criminal case is found *not guilty*, however, the prosecutor generally cannot appeal to a higher court because the U.S. Constitution states, "Nor shall any person be subject for the same offense to be twice put in jeopardy."

APPENDIX VIII
ABBREVIATIONS

APA—Administrative Procedure Act
CFR—Code of Federal Regulations
FBI—Federal Bureau of Investigation
FSM—Forest Service Manual
GAO—General Accounting Office
GSA—General Services Administration
LEMARS—Law Enforcement Management Reporting System
NCIC—National Crime Information Center
OGC—Office of the General Counsel
OIG—Office of the Inspector General
USC—United States Code
USDA—United States Department of Agriculture

GLOSSARY

Act.—Another name for a statute.

Affidavit.—"A written or printed declaration or statement of facts, made voluntarily, and confirmed by the oath or affirmation of the party making it, taken before a person having authority to administer such oath or affirmation" (Black 1979).

American legal system.—A set of four interrelated components—legislative groups, legislated laws, enforcement agencies, and courts—whose interactions formalize standards of behavior for members of our society.

Answer.—A formal, written statement by the defendant, in response to the plaintiff's complaint, that sets forth the grounds of his or her defense.

Appeal.—A "resort to a superior (i.e., appellate) court to review the decision of an inferior (i.e., trial) court or administrative agency" (Black 1979).

Appellant.—The person who appeals a decision of a lower court to a higher court.

Appellate court.—A court that has the authority to determine whether a lower court followed the correct legal procedure when hearing and deciding a case.

Archaic laws.—Standards of human conduct no longer accepted and practiced by members of our society.

Arraignment.—A procedure whereby the defendant is brought before a judge of a major trial court to plead to the criminal charge in the indictment or information (Black 1979).

Arrest.—"The taking of a person into custody for the purpose of charging him with a crime .... An arrest is made by actual restraint of the subject or by his submission to the custody of the person making an arrest" (Germann *et al.* 1977). See also General power of arrest.

Attorney.—A person who is appointed and authorized to act in the place or stead of another. An attorney-at-law is a "person admitted to practice law in his respective state and authorized to perform both civil and criminal legal functions for clients, including drafting of legal documents, giving of legal advice, and representing such before courts, administrative agencies, boards, etc." (Black 1979).

Attorney General of the U.S.—The head of the Department of Justice and chief law officer of the Federal Government. He or she represents the U.S. in legal matters and advises the President and heads of the executive departments of the Government (Off. of the Fed. Reg. 1981).

Bail.—Either a cash deposit left with the court by an individual accused of a crime or security posted by a licensed bonding company (or others) guaranteeing the individual's court appearance.

Bailiff.—An officer of the court who executes the court's demands and secures order in the courtroom (Black 1979).

Bill of particulars.—In a civil case, a bill of particulars, if furnished by the plaintiff, gives detailed information regarding the cause of action in the case; if furnished by the defendant, it gives detailed information contrary to the plaintiff's demands for restitution.

Bind over.—In this publication, an act of transferring a case from a lower court to a higher court for trial after a finding of probable cause indicating that the defendant committed a crime.

Booking.—An administrative record of arrest that involves entering the date, the time, the suspect's name and address, the specific charge against him or her, and other relevant facts on a police "blotter."

Breach of contract.—The failure of one party to do what he or she had agreed to do in a contract.

Brief.—A written document, generally prepared by an attorney arguing a case in court, which may contain a summary of the facts of a case, pertinent

laws, issues to be tried, a synopsis of evidence and witnesses to be presented, how the law applies to facts supporting the plaintiff's or defendant's position, etc. An *appellate brief*, filed with an appellate court, is a written argument explaining how a trial court either acted incorrectly (appellant's brief) or acted correctly (appellee's brief) in a case.

Burden of proof.—In a civil case, the plaintiff's need to prove facts in a case by a preponderance of evidence. In a criminal case, the state's need to prove the defendant is guilty beyond a reasonable doubt.

Capital offense (capital case or crime).—A crime carrying a penalty of death.

Case.—"A general term for an action, cause, suit, or controversy, at law ... ; a question contested before a court of justice" (Black 1979).

Cause of action.—A person's right, under law, to institute a court case; "the fact or facts which give a person a right to judicial relief" (Black 1979).

Charge.—To indict or formally accuse a person of an offense; "to instruct a jury on matters of law" (Black 1979).

Charged law violator.—An individual or organization formally charged in a criminal case or sued for a wrongdoing in a civil case.

Citation.—A document that commands a suspect to appear before a certain court on a specified day; it describes the nature and location of the offense.

Civil law.—The portion of the law that defines and determines the personal and property rights of an individual.

Civil process.—The procedure through which a person (or organization) with a claim against another can institute an action (lawsuit) in court and seek a remedy for a violation of personal and/or property rights.

Claim.—"A demand for something rightfully or allegedly due; assertion of one's right to something" (*Webster's New World Dictionary* 1968).

Code.—"A systematic compilation of both statutory law and the law handed down by the judges in their decisions" (Bahme 1976).

Code of Federal Regulations (CFR).—An arrangement, under 50 titles, of detailed regulatory laws (regulations) enacted by Federal administrative agencies.

Collateral.—A sum of money set by a court and posted by a defendant on the condition that such money will be forfeited if the defendant waives a court appearance. It is, basically, paying a fine (in lieu of another kind of penalty) for a wrongful act.

Common law.—Basically unwritten, judge-made law based on Anglo-Saxon customs and judicial precedent (Hemphill and Hemphill 1979).

Commuted sentence.—A sentence that is reduced or changed by the executive branch of government to one that is less severe.

Complainant.—A person who files a complaint or instigates prosecution by charging a person with a specific offense.

Complaining witness (prosecuting witness).—"The ... person upon whose complaint or information a criminal accusation is founded and whose testimony is mainly relied on to secure a conviction at the trial" (Black 1979).

Complaint.—A formal, written accusation charging a person with a civil or criminal offense.

Constitution.—See U.S. Constitution.

Contempt.—In civil cases, a failure to comply with a court order (an offense against the party in whose behalf the court order was issued). In criminal cases, an act done in disrespect of the court or its process (an offense against the dignity of the court).

Contract.—A definite agreement, written or oral, between two or more competent persons that creates a legal obligation and is enforceable in the courts.

Conversion.—The wrongful taking of someone else's property for one's own use.

Conviction.—"The result of a criminal trial which ends in a judgment or sentence that the accused is guilty as charged" (Black 1979).

Cooperative Law Enforcement Program.—A program involving both the Forest Service and other law enforcement agencies that is designed to protect forest-using people and their property.

Corrections.—Agencies responsible for the discipline, treatment, and rehabilitation of incarcerated law violators and for their supervision after they leave correctional institutions.

Counterclaim.—A claim made by a defendant in a civil case in response or opposition to the claim of the plaintiff.

Court.—An organized body of individuals (one or more judges and often a jury) "with defined powers, meeting at certain times and places," primarily to hear and decide cases and other matters brought before it (Black 1979). Note: Sometimes the words "court" and "judge(s)" are used synonymously.

Crime.—A public wrong considered an injury to the order and peace of our entire society. This injury could come from "an act committed or omitted in violation of a law forbidding or commanding it"

and is punishable, upon conviction by fine, imprisonment, removal from office, disqualification to hold office, and/or death (Black 1979).

Criminal law.—The portion of the law that defines and determines acts contrary to the public good. Criminal law consists mainly of formal statutes and ordinances that delineate offenses and their punishments.

Criminal process.—A method by which the legal system handles individual criminal cases; an orderly progression of events starting with a detected and reported crime and concluding with the unconditional release of a law violator.

Cross-examination.—Questioning of a witness, by the opposite side's attorney, in order to test the witness's testimony and credibility.

Current laws.—Standards of human conduct currently accepted and practiced by members of our society.

Damages.—A monetary compensation awarded in civil court to a person who has suffered a loss through the actions of another.

Defendant.—An individual who has been accused of an offense by an individual in a civil case and by the state (people) in a criminal case; "the person defending or denying" (Black 1979).

Deliberation.—The careful consideration of facts by a jury so that it may reach a verdict.

Demand (or demand-for-payment) letter.—A letter informing a debtor of the reason for and the amount of indebtedness, the date payment is due, the interest that will be charged for late payment, and other consequences of failure to cooperate.

Demurrer.—An application to the court to test the legal strength of the complaint and, if the complaint is found wanting, to order it corrected or dismissed.

De novo.—As new. Because many inferior courts do not keep records of their proceedings, a case tried over again in higher court will be tried "as new."

Direct examination.—The initial interrogation or examination of a witness by the party on whose behalf he or she is called (Black 1979).

Directed verdict.—In most cases, a verdict ordered by the judge in favor of the defendant when the plaintiff/prosecutor has failed to present sufficient evidence.

Discharge.—To release from custody, prison, or

lled disclosure proceedings or examinations before trial).—Pretrial procedures that help an attorney for one side obtain facts and information about the case from the other party in order to prepare the case for trial.

Docket.—A list of cases waiting to be tried.

Duces tecum.—See Subpoena *duces tecum.*

Enacted law (legislated law).—Law that has come into existence through legislative action.

Enforce.—"To strengthen; urge with energy; constrain or compel; carry out effectively" (*Webster's New Collegiate Dictionary* 1975).

Enforcement agency.—Any governmental agency that is wholly or partly responsible for carrying out the mandate or command of law.

Equity.—A set of rules and "principles ... applied when common law [does] not provide a suitable remedy for a particular wrong" (Kempin 1973).

Evidence.—"All the factual material that each side will present to prove its case and disprove the opposition's" (Dolan 1972).

Federal Bureau of Investigation (FBI).—The principal investigative arm of the U.S. Department of Justice.

Felony.—A major law violation (crime) punishable by death or by imprisonment (usually for more than a year) in a Federal or State penitentiary.

Fine.—A monetary punishment or penalty imposed by a court on a person guilty of a civil or criminal offense.

Forest Officers.—As used in this publication, USDA Forest Service employees who receive a minimum of 1 week (Level II) or 3 weeks (Level III) of law enforcement training and spend 5 to 20 percent of their time in routine enforcement duties.

Garnishment.—The process whereby a court orders a defendant's employer (or others owing the defendant money or controlling the defendant's property) to pay the defendant's money to the plaintiff until restitution is made.

General Accounting Office (GAO).—The General Accounting Office, under the control and direction of the Comptroller General of the United States,

> ... has the following basic purposes: to assist the Congress, its committees, and its Members in carrying out their legislative and oversight responsibilities, consistent with its role as an independent nonpolitical agency in the legislative branch; to carry out legal, accounting, auditing, and claims settlement functions with respect to Federal Government programs and operations as assigned by the Congress; and to make recommendations designed to provide for more efficient and effective Government operations (Off. of the Fed. Reg. 1981).

General power of arrest. — —

> The power to suppress with force all breaches of the peace, riots, tumult and unlawful assemblies, power to serve all criminal process, including the power to arrest a person without a warrant if the person is apprehended in the process of committing an unlawful act or if he or she obtains "speedy information" by other persons (Gottfredson *et al.*, eds. 1978).

General Services Administration (GSA).—An agency responsible for the management of the Federal Government's property and records.

Grand jury.—A group of summoned and sworn citizens who listen to facts and accusations in a criminal case and decide whether there is evidence to hold an accused person for trial. "It is an accusatory body and its function does not include a determination of guilt" (Black 1979).

Hearing.—See Preliminary hearing.

Hung jury.—A jury that cannot come to a unanimous decision (when one is required).

Imprisonment.—A "restraint upon a person's personal liberty" (Black 1979). See Appendix III.

Incarcerate.—To imprison or jail.

Incarcerated law violator.—An individual serving a sentence in a jail, prison, or other correctional institution.

Incendiarism.—In this publication, this term refers to willfully setting a wildfire on someone else's property.

Incendiarist.—One who willfully sets a wildfire on someone else's property.

Indictment.— "A formal, written accusation originating with a prosecutor [but] issued by a grand jury against a [person] charged with a crime" (Black 1979).

Inferior court.—Generally, a trial court, having original, limited jurisdiction, that is subject to the review or correction of higher (superior) courts.

Information.—A document (without an indictment), filed by a prosecutor, charging an individual with a criminal offense.

Initial appearance.—The first appearance of a defendant charged with a crime before a judge or magistrate who "advises the defendant of the charges against him and of his rights, decides upon bail and/or other conditions of release, and sets the date for a preliminary hearing" (Black 1979).

Injunction.—A court command or order to a defendant to do or refrain from doing certain actions in the future.

Interrogatories.—In a civil case, a type of discovery consisting of questions about a case that are written by one side (e.g., plaintiff) and submitted to a witness or the individual on the other side (e.g., defendant).

Jail.—A building designated by law or regularly used to confine persons, convicted of misdemeanors or awaiting trial, for short periods of time (more than 48 hours but rarely over a year).

Judge.—"A public official authorized to preside over and decide questions brought before a court" (Rosenbauer 1978).

Judgment.—The final decision of a judge resolving a dispute and determining the rights and obligations of the parties.

Jurisdiction.—The authority or legal power of a particular court (State or Federal) to hear and decide certain cases within a given geographic area. Jurisdiction can be divided into three components—territorial, personal, and subject matter (Chamelin *et al.* 1975) and can be classified as original or appellate. See Appendix IV.

Jury.—A body of citizens selected to hear and decide a case in a civil or criminal court. They inquire into certain matters of fact and declare the truth based on evidence laid before them (Black 1979).

Law enforcement.—The carrying out of a mandate or command of law; execution of a law or putting a law into effect.

Law Enforcement Officers.—Highly trained Forest Service employees who spend 10 to 50 percent of their time in law enforcement activities and have duties similar to uniformed patrol officers.

Law enforcers.—People who have responsibilities to carry out the mandate or command of law, using a variety of measures to encourage or, in some cases, force people to live by standards of conduct considered necessary to protect individuals and communities in our society.

Laws.—Standards of human conduct. They may change, as society's needs and desires change through custom and usage, judicial and religious interpretation, enactment, and other means.

Lawsuit.—An action or proceeding in a civil court, also referred to as litigation, instituted by an individual to compel another to do him or her justice.

Legal system.—See American legal system.

Legislated laws.—In the broadest sense, enacted laws (statutes, ordinances, regulations) made or given by authorized Federal, State, or local legislative groups.

Legislative group.—A body or assembly of persons that formulates and enacts statutes, ordinances, and regulations for a government (Federal, State, local).

Magistrate.—In this publication, a public judicial officer who has many, but not all, of the powers of a judge.

Mala in se.—Wrongs in themselves. The nature of certain crimes such as robbery or murder is considered inherently evil.

Mala prohibita.—"Acts which are made *offenses* by ... laws and *prohibited* as such. Acts or omissions which are made criminal by statute but which, of themselves, are not criminal" (Black 1979).

Mandatory/conditional release.—A release from incarceration, freeing all or designated prisoners 6 months or more before their sentences expire. This release allows prisoners to adjust, under supervised conditions, to life outside prison walls.

Misdemeanor.—Any crime that is not a felony is generally called a misdemeanor. Misdemeanors are punishable by imprisonment for 1 year or less in a city or county jail or by a fine of $1,000 or less, or both. Sometimes they are classified as high or low (petty offense). A high misdemeanor carries more than a 6-month sentence and a fine greater than $500, or both. For a definition of a low misdemeanor, see Petty offense.

National Crime Information Center (NCIC).—A clearing house of information on individuals' criminal histories and stolen Governmental property. It is located in the Washington, DC, headquarters of the FBI.

Negligence.—"The failure to use such care as a reasonably prudent and careful person would use under similar circumstances; it is the doing of some act which a person of ordinary prudence would not have done under similar circumstances or failure to do what a person of ordinary prudence would have done under similar circumstances ... It is characterized chiefly by inadvertence, thoughtlessness, inattention, and the like while 'wantonness' or 'recklessness' is characterized by willfulness" (Black 1979).

Nolo contendere.—No contest. "A plea in a criminal case that has a similar legal effect as pleading guilty," except that the defendant does not have to admit or deny the charges (Black 1979). According to Black (1979), the primary difference between a plea of guilty and a plea of *nolo contendere* is that the latter may not be used against the defendant in a civil action based on the same acts.

Notice.—As used in this publication, a public document intended to inform the public of some proceeding in which their interests are involved or informing them of some fact that is their right to know and the duty of the Government to communicate (Black 1979). From a Forest Service standpoint, notices are statements, published in the *Federal Register*, of general policy or interpretations of statutes concerning National Forest administration.

Oath.— A solemn formal declaration to tell the truth "which renders one willfully asserting untrue statements punishable for perjury" (Black 1979).

Offense.—Although this term usually refers to a felony or misdemeanor, we use it here to mean any violation of civil or criminal law.

Office of the General Counsel (OGC).—The principal legal advisor in the USDA.

Office of the Inspector General (OIG).—The key investigative authority in the USDA.

Order.—A rule or regulation; a mandate, command, or direction authoritatively given. From a Forest Service perspective, it is a temporary restriction on public activities, issued by designated authorities in the Agency, that has the force and effect of law.

Ordinance.—A written law generally enacted by lesser governmental groups such as city and village governments and county and township boards.

Pardon.—An "act of grace" or forgiveness from the executive branch of government that releases an offender from the entire punishment prescribed for the offense (Black 1979).

Parole.—A conditional release of an incarcerated law violator (generally under the supervision of a parole officer) who has served part of the jail/prison (or other correctional institution) term to which he or she was sentenced (Black 1979).

Petit jury.—"The ordinary jury for the trial of a civil or criminal action; so called to distinguish it from the grand jury" (Black 1979).

Petty offense.—A low misdemeanor punishable by imprisonment for not more than 6 months or a fine of not more than $500, or both.

Plaintiff.—"The party who complains or sues in a civil action .... The prosecution (i.e., State or United States) in a criminal case" (Black 1979).

Plea.—In a criminal action, the defendant's response to a charge (guilty, not guilty, or *nolo contendere*).

Pleading.—The formal allegations, made by both parties to a lawsuit, in their respective claims and defenses. The pleadings include the complaint, an answer, a reply to a counterclaim, etc. (Black 1979).

Plea bargaining.—"The process whereby the accused and the prosecutor in a criminal case work out a mutually satisfactory disposition of the case subject to court approval" (Black 1979).

Police.—Generally, sworn employees (usually public) who have taken an oath of office (received formal authority) and possess the general power of arrest.

Potential laws.—Standards of human conduct that could develop or become actual (as society's needs and desires change) but do not exist now.

Prayer (prayer for relief).—In civil cases, a demand that names the damages or relief to which the plaintiff believes he or she is entitled.

Preliminary hearing (also called preliminary examination).—An optional procedure held before a judge or committing magistrate who decides, in light of the evidence presented by the prosecutor, whether or not the crime charged did occur and whether or not it's reasonable to believe that the accused may have committed it (Germann *et al.* 1977).

Preponderance of evidence.—"Evidence which is of greater weight or more convincing than the evidence which is offered in opposition to it" (Black 1979).

Presentence investigation.—A report, prepared and submitted to the court by a probation or parole officer after an investigation of the background of a proven law violator, that recommends a sentence and treatment programs.

Prevention.—To keep an act or event from happening; to hinder, prohibit, impede, or preclude. From a law enforcement standpoint, prevention can be defined as activities that attempt to stop or reduce the occurrence of unlawful acts, including wildfire ignitions.

Prison (penitentiary).—An institution used to incarcerate persons convicted of more serious crimes (i.e., felonies) for more than 1 year.

Probable cause.—Having more evidence *for* than *against* the possibility that an individual did a particular wrong.

Probation.—A sentence given to a proven law violator by a court releasing the defendant into society under the supervision of a probation officer (Black 1979).

Prosecute, prosecution.—In the criminal process, to initiate an action against someone and follow it through to an ultimate conclusion; the continuous followup by the state "of a person accused of a public offense with a steady and fixed purpose of reaching a [court] determination of the guilt or innocence of the accused" (Black 1979). Prosecution is also used as a synonym for prosecutor.

Prosecutor (e.g., prosecuting attorney, district attorney, state's attorney).—"One who prosecutes another for a crime in the name of the government" (Black 1979).

Proven law violator.—An individual or organization that has been found guilty of a wrongdoing.

Public service.—Activities of law enforcement personnel that serve the needs of the general public or contribute to the comfort and convenience of an entire community.

Punishment.—Any fine, penalty, or confinement inflicted on an offender through judicial procedure.

Rebuttal.—Evidence introduced during a trial that refutes evidence previously offered by the opposing party.

Regulation.—A written law established by a Federal, State, or local administrative agency; a "rule or order having force of law issued by executive authority of government" (Black 1979).

Remand.—To send back. To send a case from an appellate court back to the same court from which it came in order to have some further action taken on it there (Black 1979).

Remedy.—"The means by which a right is enforced or the violation of a right is prevented, redressed, or compensated" (Black 1979).

Repression.—Law enforcement activities, initiated during and/or after offenses, intended to subdue, curb, or control law violators.

Restitution.—"The act of making good or giving equivalent for any loss, damage or injury; an indemnification" (Black 1979).

Sentence.—A formally pronounced judgment by a court, ending a case, that imposes a punishment on a proven law violator; it declares the legal consequences of a defendant's guilt.

Settlement.—"An agreement by which parties having disputed matters between them reach or ascertain what is coming from one to the other" (Black 1979).

Sheriff.—The chief administrative and executive officer of a county. County sheriffs' duties can cover a broad spectrum of law enforcement. For example, sheriffs can be responsible for everything from assessing property and collecting taxes to determining the causes of unusual deaths in the county and carrying out a death penalty imposed by a court.

Small Claims Court.—A special court that quickly, informally, and inexpensively hears and decides on cases involving small claims. " Jurisdiction ... is usually limited to collection of small debts and accounts. Proceedings are very informal with parties normally representing themselves" (Black 1979).

Special Agents.—Full-time Forest Service law enforcement employees responsible primarily for investigating criminal acts. One Special Agent in each Region directs the Regional Law Enforcement Program.

Specific performance.—A court order requiring the defendant *to do* the act he or she promised to do in a contract.

Stare decisis.—From the Latin, "let what is decided stand." This "doctrine of precedent," the essence of common law, states that when a court has laid down a principle of law that applies to a certain set of facts, the court "will adhere to that principle and apply it to all future cases, where [the] facts are [essentially] the same" (Black 1979).

Statute of limitations.—A time limit in which one can bring a civil or criminal action against another.

Statutes or statutory laws.—Written laws generally enacted by a legislative body such as the U.S. Congress or a State legislature.

Subpoena.—"A command to appear at a certain time and place to give testimony upon a certain matter" (Black 1979).

Subpoena *duces tecum.*—A command to appear in court with pertinent documents and exhibits.

Summons.—"A written document that notifies an individual that he has been charged with an offense and orders him to appear in court at a certain time and date to answer the charge" (Chamelin *et al.* 1975).

Superior court.—A court of general, original jurisdiction and/or an appellate court that exercises control or supervision over a system of lower courts (Black 1979).

Supreme Court of the United States.—The highest tribunal (and generally the court of last resort) in our dual system of courts (State and Federal).

Surrebuttal.—Evidence presented to refute evidence offered during a rebuttal.

Suspected law violators.—Individuals or organizations perceived to have done something wrong, whether or not they have actually broken a law.

Suspended sentence.—A sentence given formally after conviction but not actually served by the defendant.

Testimony.—Evidence given in a court by a witness under oath.

Tort.—An injury that one person, either intentionally or negligently, does to the body, property, or reputation of another (Dolan 1972).

Trespass.—"An unlawful interference with one's person, property, or rights" (Black 1979).

Trial.—A court examination and determination (either criminal or civil) of the issues between two parties.

Trial court.—Usually the first court to hear a civil or criminal case, determine the facts about an issue, and apply the law to those facts. Also known as inferior courts or courts of original jurisdiction.

True bill.—An indictment; "the endorsement made by a grand jury when they find sufficient evidence to warrant a criminal charge" (Black 1979).

United States Code (USC).—An arrangement, under 50 titles, of statutes passed by Congress.

United States Code Annotated.—A quarterly publication that updates the USC before the annual supplements are published by the Government Printing Office.

United States Statutes at Large.—A complete text of Federal statutes arranged in chronological order of signing or approval.

U.S. Attorneys.—Department of Justice legal advisors stationed in various judicial districts around the country. They "prosecute federal cases and represent the United States in civil cases" (Berkley *et al.* 1976).

U.S. Constitution.—The supreme law of the United States. It established the character and concept of our Government, including vesting legislative powers in a Congress. The Constitution laid "the basic principles to which its internal life" conforms, organized the Government, regulated, distributed, and limited the functions of its branches, and prescribed "the extent and manner of the exercise of sovereign powers" (Black 1979).

U.S. Courts of Appeals.—Courts that review orders issued by administrative and regulatory agencies for errors of law and hear both civil and criminal Federal cases on routine appeal from U.S. District Courts within their geographic areas (circuits).

U.S. District Courts.—The primary Federal trial courts that hear and decide Federal civil and criminal cases. There are 90 U.S. District Courts and 5 U.S. Territorial Courts.

U.S. Magistrates.—Judicial officers, appointed by District Court judges, who have some, but not all, the powers of judges. They conduct many of the preliminary or pretrial proceedings in civil and criminal cases and try, without a jury, petty offenses (Berkley *et al.* 1976).

U.S. Marshals Service.—An organization within the Department of Justice which performs Federal law enforcement functions for the Attorney General. U.S. Marshals supervise "federal prisoners and serve court writs and orders" (Berkley *et al.* 1976).

Unlegislated laws.—Laws, both written and unwritten, based on tradition and secular and religious principles, which have not been enacted by legislative groups. Two types of unlegislated laws are common law and equity.

Venue.—"Designates the particular county or city in which a court with jurisdiction may hear and determine [a] case" (Black 1979).

Verdict.—A formal decision of guilt or innocence made by a jury and presented to the court after the jury has deliberated the facts presented before it during a trial.

Vindicate.—"To clear of suspicion, blame, or doubt" (Black 1979).

Violation.—An offense, breach, or disregard of civil or criminal law.

Violation notice.—A citation, issued under the local rules of a U.S. District Court, requiring a violator to pay a fine or to appear before the local U.S. Magistrate for trial.

Waiver.—"Intentional or voluntary relinquishment of a known right" (Black 1979), e.g., waiving a right to a trial by jury or a grand jury indictment; abandoning a claim or charge against another party.

Warning.—A verbal or written notice from a law enforcement officer giving admonishing advice to an offender and calling his or her attention to dangers of which he or she may not be aware. Warnings are generally issued if violations occurred due to inadvertence, misunderstanding, or misinformation.

Warrant.—As used in this publication, a written order on behalf of the state, based on a complaint, that commands a law enforcement officer to arrest an individual and take him or her before a magistrate (Black 1979).

Wildfire.—An unplanned, wildland fire requiring suppression action as contrasted with a prescribed fire burning within prepared lines enclosing a designated area, under prescribed conditions; a free-burning fire unaffected by fire suppression measures.

Witness.—Any person who has personally observed an act; an individual who testifies under oath to what he or she has seen, heard, or otherwise observed (Black 1979).

Writ.—"An order issued from a court requiring the performance of a specified act, or giving authority to have it done" (Black 1979).

Writ of execution.—An order, issued by a court to enforce a money judgment, that directs a law enforcement officer to seize and sell certain property of the defendant and to use the proceeds to pay the judgment.

Writ of *habeas corpus*.—As used in this publication, an order from the court "commanding that the person detaining another produce the prisoner" (Germann *et al.* 1977).

INDEX

A

Act, 6, 29
  (*see also* Statute)
  Federal Claims Collection, 6, 17
  Forest Service law enforcement, 9-10
  wildfire, 6, 20, 29-30
Affidavit, 10, 33
Answer, 33, 45
Appeal, 13, 14
  (*see also* Appellant; Appellate court)
  after civil case, 35, 46
  after criminal case, 43-44, 46
Appellant, 35, 44
Appellate court
  in civil case, 35
  in criminal case, 43-44
  Federal, 13, 14
  jurisdiction, 30, 43
  State, 14
Arraignment, 42, 42n
Arrest, 36, 40, 7n
  (*see also* Warrant)
  in Forest Service law enforcement, 10, 11, 20
  general power of, 7n
Attorney, 9
  OGC, 11, 17, 18-19
  role in civil process, 33-35, 44-45
  role in criminal process, 40-43, 44-45
  U.S. (*see* U.S. Attorney)
Attorney General, U.S., 9, 11

B

Bail, 40n
Bailiff, 12
Bill of particulars, 33
Booking, 40
Breach of contract (*see* Contract)
Brief, 35

C

Charge (*see* Arraignment; Complaint; Indictment; Information; Initial appearance; Summons)
  answer to, 45
  by judge to jury, 35, 43
Charged law violator, 3
  (*see also* Civil process; Criminal process)
  in criminal process, 10
Citation, 40
Civil case (*see also* Civil process)
  comparison with criminal case, 44-46
  court role and jurisdiction in, 13, 14
Civil law, 5
  (*see also* Law)
Civil process, 15-19, 30-36, 15n
  comparison with criminal process, 44-46
  Forest Service, 16-17
    demand-for-payment process in, 17-19

Claim, 16, 18n
counterclaim, 33
by Forest Service, 6, 17-19, 16n, 17n, 18n
Claims Officer, 17, 18, 18n
Code, 5
(*see also* Code of Federal Regulations; Statute, U.S.)
Code of Federal Regulations (CFR), 5, 29, 29n
(*see also* Law)
Common law, 3
Commuted sentence, 44
Complainant, 44
Complaint, 33, 36
filed by Forest Service, 20-21
Contract, 15
(*see also* Civil process)
breach of, 15, 16
against Forest Service, 16-17, 17n
specific performance of, 16
Corrections, 9, 44
(*see also* Imprisonment; Jail; Punishment)
Court, 1, 12-15
(*see also* Appellate court; Jurisdiction)
Federal, 13-14
(*see also* specific names of U.S. Courts)
Forest Service and, 14-15
State, 14
Crime, 5, 19, 36
(*see also* Criminal process)
against Forest Service, 20-21
increase in, 21-22, 23
magnitude of, 24-25
problems preventing, 23
recommendations for decreasing, 23-24
classifications of, 19n
(*see also* Felony; Misdemeanor)
Criminal case (*see also* Criminal process)
comparison with civil case, 44-46
court role and jurisdiction in, 13, 14, 15, 30
prosecution of (*see* Prosecute/prosecution)
Criminal law, 5, 19, 28
(*see also* Law; Regulation; Statute)
Criminal process, 19-21, 36-44
(*see also* Prosecute/prosecution)
comparison with civil process, 44-46
Forest Service, 20-21

D

Damages, 16
(*see also* Claim)
claimed by Forest Service, 17
failure to pay, 36, 45
Defendant
in civil process, 30-36, 44-46, 15n
in criminal process, 36-44, 44-46, 40n, 41n, 43n
requirement of, by court order, 16
Demand-for-payment process, 17-19
Demurrer, 33
Directed verdict (*see* Verdict)
Discovery proceedings, 33
District attorney (*see* Attorney)
Docket, 33

E

Enforcement (*see* Law enforcement)
Enforcement agency (*see* Law enforcement agency)
Equity, 3
Evidence
during a civil trial, 34-35, 45
during a criminal trial, 42, 43, 45
in a Forest Service claim, 17, 18
preceding a criminal trial, 36, 41-42, 41n
Examination
cross-, 34, 42, 43
direct, 34, 42, 43
preliminary (*see* Preliminary hearing)

F

Federal Bureau of Investigation (FBI), 11
Federal Claims Collection Act, 6, 17
Felony, 19, 41
(*see also* Crime)
against the Forest Service, 20, 21, 24
Fine, 19, 43
for civil contempt, 36
for crime, 43, 44, 45
forfeiture of collateral for, 14n
for misdemeanor, 14, 19
for wildfire offenses, 6, 10, 20
wildfire violations resulting in, 25
Fire (*see* Wildfire)
Forest Officer, 10, 11, 22n
(*see also* Law enforcement)
law enforcement activities of, 20-21, 14n, 20n, 21n
statutory law enforcement authority of, 10

G

Garnishment, 36
General Accounting Office (GAO)
findings and recommendations of, 22, 23, 24, 23n
Grand jury, 41-42, 45
(*see also* Indictment)
in Forest Service prosecutions, 21
role in criminal process, 36, 41n

I

Imprisonment, 30
(*see also* Corrections)
for civil offense, 36

for crimes, 19, 43, 44
releases from, 44
for wildfire offenses, 6, 10
Incarcerated law violator, 3, 7, 44
Incendiarism/incendiarist, 13, 19, 24
Indictment, 41-42
(*see also* Grand jury)
Information, 21, 41
Initial appearance, 41
Injunction, 15, 16, 36

J

Jail, 30, 44
(*see also* Imprisonment)
as punishment for misdemeanor, 19
temporary custody in, 20
Judge, 12
activities of, in a civil trial, 34-35
activities of, in a criminal trial, 42-43
civil posttrial activities of, 35-36
and common law, 3
magistrate, 36, 40, 41
(*see also* U.S. Magistrate)
role in pretrial civil proceedings, 33-34
role in pretrial criminal proceedings, 36, 40-42
role in sentencing, 43
U.S. District Court, 13-14, 15, 42n
Judgment, 34, 35
affirmed or reversed on appeal, 35, 43-44
default, 33
enforcement of, 36
summary, 33
Jurisdiction, 12-14, 30, 43-44
Jury, 12, 34, 42, 45, 43n
grand (*see* Grand jury)
verdict, 35, 43, 45

L

Law, 3-6, 6n
(*see also* Civil law; Criminal law; Ordinance; Regulation; Statute)
Forest Service and, 5-6
legislated, 1, 3, 5, 3n
unlegislated, 3
Law enforcement, 6-12
agencies, 1, 9, 11-12, 9n
role in court of, 12
Forest Service and, 9-10, 21-26
agencies, 11-12
personnel, 10-11, 10n
Law Enforcement Management Reporting System (LEMARS), 23, 24n
Law Enforcement Officer, 10, 11, 22, 22n
(*see also* Law enforcement)
law enforcement activities of, 20, 21
Lawsuit (*see* Civil process)
Legislated law (*see* Law)
Legislative groups, 1, 3, 5, 3n

M

Magistrate (*see* Judge)
Mandatory/conditional release, 44
Misdemeanor, 14, 19, 30
(*see also* Crime)
petty offense, 19, 40, 41, 45
against Forest Service, 15, 20, 21, 24, 14n, 20n,
pretrial processing of, 41-42, 40n

N

National Crime Information Center (NCIC), 11
Negligence, 15
wildfire, 20, 25, 16n
Nolo contendere (*see* Plea)
Notice
Forest Service, 29
violation (*see* Violation)

O

Offense (*see* Crime; Felony; Misdemeanor; Violation)
Office of the General Counsel (OGC), 11, 18-19, 17n, 18n
(*see also* Attorney, OGC)
Office of the Inspector General (OIG), 11
Officer (*see* Arrest; Forest Officer; Law Enforcement; Law Enforcement Officer; Parole officer; Police; Probation officer)
Order
court, 16, 36, 40
Forest Service, 25, 29
Ordinance, 3, 5, 14, 20, 3n
(*see also* Law)
Original jurisdiction (*see* Jurisdiction)

P

Pardon, 44
Parole, 9, 44
officer, 43, 44
Petty offense (*see* Misdemeanor)
Plaintiff, 15n
in civil process, 16, 30-36, 44-46, 16n
Plea, 41, 42
Police, 7, 9
Preliminary hearing, 41, 41n
Presentence investigation, 43
Prevention
through law enforcement, 6-7, 10
wildfire, 1, 25-26
Prison/penitentiary (*see* Imprisonment)
Probation, 43, 44

officer, 30, 43
Prosecute/prosecution (*see also* Criminal process)
after violation of both Federal and State laws, 21n
Forest Service initiation of, 21
by U.S. Attorneys, 15, 21, 21n
Prosecutor (*see* Attorney)
Proven law violator, 3, 19, 30, 43, 44
(*see also* Civil process; Criminal process)
Punishment, 44
(*see also* Imprisonment; Sentence)
for violation of statutes, 19

R

Rebuttal, 43
Regulation, 3, 5, 29, 3n
(*see also* Law)
authority of USDA to make, 6
Forest Service, 9-10, 29, 29n
enforcement of, 23
violation of, 14-15, 20, 21, 24-25, 14n
wildfire, 6, 20
Remedy, 16
(*see also* Damages)
in Forest Service civil suits, 17
Repression, 7, 10
Restitution (*see* Damages)

S

Sentence/sentencing, 43
(*see also* Punishment)
commuted, 44
expired, 44
in pretrial process, 41, 42
reasons for, 30
suspended, 43, 44
for wildfire offenses, 6
Sheriff, 7, 9
Small Claims Court, 18, 18n
Special Agent, 10-11, 22, 10n, 22n, 24n
(*see also* Law enforcement)
law enforcement activities of, 17, 19, 20, 21, 21n
Specific performance (*see* Contract; Remedy)
Statute, 3, 5-6, 28-29, 3n
(*see also* Act; Law)
criminal, 19
Forest Service, 5-6, 9-10, 9n
enforcement of, 23
violations of, 14, 20, 21, 24, 25
wildfire, 6, 20, 24, 25, 29-30
U.S., 5, 28
Statute of limitations, 33, 36
Subpoena, 15, 45
duces tecum, 34
Summons, 33, 36, 40
issued by courts, 15, 20
served by law enforcement personnel, 11, 15, 20
Supreme Court
State, 14
United States, 13
Surrebuttal, 43
Suspected law violator, 3, 7
(*see also* Civil process; Criminal process)
in criminal process, 10, 36, 40

T

Tort, 15, 16, 16n
against Forest Service, 16-17
Trespass, 15
against Forest Service, 16-17, 22, 23
criminal, 19
Trial, 34-35, 42-43, 43n
(*see also* Civil process; Court; Criminal process)
True bill, 41

U

U.S. Attorney, 11, 14
(*see also* Attorney)
and relation with Forest Service, 15, 21n
civil process, 17, 19
criminal process, 21
U.S. Attorney General, 9, 11
U.S. Code (USC) (*see* Statute, U.S.)
U.S. Court of Appeals, 13
U.S. Court of Claims, 14
U.S. District Court, 13-14
Forest Service and, 14-15, 19, 21, 14n
judge, 13, 15, 42n
U.S. Magistrate, 13-14, 21n
Forest Service and, 14-15, 20, 14n
role in criminal process, 36, 42n
U.S. Marshal, 11, 14, 20-21
U.S. Statutes at Large (*see* Statute, U.S.)
U.S. Supreme Court (*see* Supreme Court)
U.S. Territorial Court, 13
(*see also* U.S. District Court)
Unlegislated law (*see* Law)

V

Verdict, 45, 43n
in civil case, 35
in criminal case, 43
directed, 34-35, 42-43
Violation (*see also* Crime)
civil, 5, 15, 15n
Forest Service
FBI authority to investigate, 11
notice, 11, 20, 21
prevention of, 25-26
response to, 14, 20-21, 20n, 21n
wildfire, 20, 24-25
notice, 40

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W

Waive/waiver, 40-41, 42
  by posting collateral, 14n
  of preliminary hearing, 41n
Warning, 20, 40
  for fire offenses, 25
Warrant, 11, 36, 40, 40n, 41n
  (*see also* Arrest; U.S. District Court; U.S. Magistrate)
Wildfire, 1
  claim, 18
  offense, 20
    (*see also* Act; Crime; Regulation)
    investigation of, 21n
    role of law enforcement in, 24-25
  trespass, 16-17
Witness
  Forest Service employee as, 19, 21
  in civil case, 34
  in criminal case, 20, 36, 41, 42, 43, 44, 45
  in grand jury investigations, 45
Writ
  of execution, 36
  of *habeas corpus*, 40

Donoghue, Linda R.; Paananen, Donna M.
The legal system, the U.S. Forest Service, and human-caused wildfires. Res. Pap. NC-248. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 57 p.

Presents an overview of the American legal system; describes the relations and interactions between the Forest Service and legal system components and processes; discusses how individuals enter, move through, and leave the legal system; and describes the current status of Forest Service law enforcement efforts directed at wildfire violations.

KEY WORDS: Law, civil process, criminal process, law enforcement, courts, wildfire prevention, and wildfire ignitions.

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Height Growth of Red Pine on Fine-Textured Soils

David H. Alban and Donald H. Prettyman

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Height growth of red pine on fine-textured soils. Res. Pap. NC-249. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 6 p.

Height growth was determined by stem analysis for red pine in 12 natural and 10 planted stands on well-drained, fine-textured soils. Growth closely followed the Gevorkiantz site index curves. When calculating site index, an age adjustment is desirable if the trees take longer than 8 years to attain breast height.

KEY WORDS: Alfisols, growth intercept, site index, *Pinus resinosa*.

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HEIGHT GROWTH OF RED PINE ON FINE-TEXTURED SOILS

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Growth and yield for red pine can be estimated from published reports if site index is known (Benzie 1977, Buckman 1962). Accurate estimates of site index depend on the site index curves depicting the actual tree height growth throughout the life of a stand. If tree height growth patterns differ from that of the site index curves, the "apparent site index" will vary depending upon the age at which the measurements are taken.

The red pine site index curves are harmonized (Gevorkiantz 1957). That is, region-wide height and age data were used to construct a single average height-age curve. From this curve a family of curves representing good to poor sites were developed by proportionally adjusting the average curve. For many species harmonized curves have been shown to be inadequate and height growth for them is better described by polymorphic curves—those developed specifically for different soils, locations, or site productivity classes (Carmean 1975). For red pine the height growth of most stands in the Lake States has been shown to closely follow the Gevorkiantz site index curves (Alban 1979, Van Eck and Whiteside 1963). However, examples of significant deviations from the site index curves have been shown for poorly drained soils (Richards *et al.* 1962) and for some sites with compact subsoils (Van Eck and Whiteside 1963).

Most natural stands of red pine in the Lake States occur on sandy soils (Eyre and Zehngraff 1948), and it was primarily from such stands that the Gevorkiantz site index curves were developed. Hence it is not surprising that most natural stands closely follow the site index curves. However, many red pine plantations have been established on finer-textured soils in the Northeast and North-central states (DeMent and Stone 1968, Stone 1976, Wilde *et al.* 1965). No systematic evaluation has been made of the applicability of the site index curves to the growth of red pine on these fine-textured soils. Now that many of the plantations are approaching 50 years of age, such an evaluation is possible; the purpose of this paper is to make that evaluation.

Study Areas

Ten planted and 12 natural stands of red pine ranging in age from 44 to 86 years and in site index from 39 to 68 feet were sampled (table 1). The 12 natural stands were part of an earlier study (Alban 1979) and were the only natural red pine stands found on fine-textured soils out of 250 stands examined. All stands were in Minnesota except for one in northwestern Wisconsin. Eight of the stands had been thinned within the last 15 years, but this should not affect the height growth of the remaining dominant and codominant trees (Day and Rudolph 1972, Von Althen *et al.* 1978).

The soils were all well drained and finer textured than commonly associated with red pine. Surface soil texture ranged from sandy loam to clay with silt + clay of from 34 to 85 percent (table 1). Most soils were finer textured in the subsoil than in the surface soil, but two stands had sands below the surface soil and two were underlain by bedrock at less than 8 inches (table 1). Most soils were in the order Alfisol (Soil Survey Staff 1975).

Methods

The soils of each study area were identified by soil scientists from the Superior or Chippewa National Forests or the Soil Conservation Service. Surface soil samples were collected from 1-4 soil pits per stand to determine particle size.

Table 1.—*Vegetation and soil characteristics of study areas*

Stand age	Basal area	Site index[1]	Time to reach breast height	Silt + Clay in surface soil	Soil
	Ft²/A	*Feet*	*Years*	*Percent*	
			Planted Stands		
48	187	68	8	52	Unnamed (Glossic Eutroboralf)
48	156	65	10	55	Unnamed (Glossic Eutroboralf)
49	145	64	10	57	Unnamed (Glossic Eutroboralf)
46	222	62	10	59	Unnamed (Glossic Eutroboralf)
46	224	64	11	58	Unnamed (Glossic Eutroboralf)
44	147	65	7	61	Unnamed (Glossic Eutroboralf)
44	157	67	6	62	Unnamed (Glossic Eutroboralf)
52	257	68	8	36	Warba (Glossic Eutroboralf)
45	179	61	6	53	Itasca (Glossic Eutroboralf)
44	171	60	8	34	Unnamed sandy loam over loam
			Natural Stands		
68	179	50	7	77	Taylor (Aquic Eutroboralf)
72	199	58	8	40	Unnamed sandy loam over loamy sand
68	235	57	8	85	Nebish (typic Eutroboralf)
70	161	59	8	66	Nebish (typic Eutroboralf)
70	191	60	7	45	Nashwauk (typic Glossoboralf)
53	190	65	7	43	Nebish (typic Eutroboralf)
58	184	62	6	51	Rockwood (typic Fragiboralf)
58	175	66	9	41	Unnamed sandy loam over sandy loam
86	133	56	7	45	Unnamed sandy loam over coarse sands
58	193	41	8	48	Quetico (Lithic Udorthent)
70	134	39	10	41	Quetico (Lithic Udorthent)
71	139	56	6	50	Unnamed sandy loam over loam

[1]Height at age 50 based on three to five felled sample trees.

In every stand DBH of each tree was measured on three 1/10 acre plots, and three to five dominant or codominant trees were felled. For planted stands, the internodes between all visible whorls were used to measure height growth, and age from seed was determined from plantation records. For natural stands, whorls were often not visible on the lower part of the stem, so the boles were sectioned (at intervals of 1 foot up to a height of 8 feet, and at 3-foot intervals thereafter and the rings were counted on each section. Total age was estimated by adding 2 years to the ring count at the stump. Previous work has shown that height growth curves constructed from measurements of internodes or from ring counts on sections are equivalent (Alban 1972). A single height-age curve was constructed for each stand by averaging the data from the three to five sample trees. For planted stands younger than 50 years, the curves were extended up to 50 years using height growth predicted from the Gevorkiantz site index curves. Only minor errors occurred from this procedure because the extrapolation was for just a few years (table 1). From the height growth curve for each stand, tree height at each age was read including age 50 (site index). The average height growth curve for each stand was compared with the Gevorkiantz site index curve as described by the equation of Lundgren and Dolid (1970):

$$\text{Height} = (\text{Site index})\,(1.956 - 2.1757e^{-0.01644\,\text{Age}}). \quad \text{(Eq. 1)}$$

This equation was developed so that at age 50 tree height equals site index. It has a maximum error in describing the site index curves of 1.4 feet (Lundgren and Dolid 1970).

For red pine only a weak relation exists between the time required for trees to attain breast height

(BH) and later height growth (Alban 1979, Day *et al.* 1960, Ferree *et al.* 1958). Weather, stock quality, planting techniques, plant competition, and animal damage may strongly affect early growth and mask the effects of site on growth. Thus to make the best possible comparison of height growth with that predicted by the site index curves, early growth must be disregarded.

By age 15 most red pine are past the age at which factors strongly affecting early growth have had their major impact (Alban 1979). Thus comparisons of height growth on fine-textured soils with site index curves are most meaningful if made at ages beyond 15 years. Such comparisons avoid the variation associated with early height growth and enable determination of the accuracy of the site index curves in describing height growth for specific stands. For each stand studied, height growth from age 15 to 50 was determined as a measure of site quality relatively free from the variable effects of early height growth. The Gevorkiantz site index curve with the same height growth from age 15 to 50 as measured for each stand was calculated from the equation of Lundgren and Dolid (1970) and the height at age 15 for that curve was determined. The entire height growth curve for each stand was then adjusted upward or downward so that actual height at age 15 corresponded to height at age 15 predicted from the Gevorkiantz curve. This procedure sets the height at age 15 for each stand equal to height at age 15 of the appropriate site index curve and facilitates graphical or statistical comparison between height growth and the Gevorkiantz site index curve.

RESULTS AND DISCUSSION

A. Height growth patterns

The adjusted height growth curves from this study closely follow the Gevorkiantz site index curves. Values are typical for four of the older natural stands representing a wide range of site indexes (fig. 1). From age 15 to 50 the maximum deviation from the site index curves was about 2 feet, and the maximum deviation was greater than 1.5 feet for only one planted and two natural stands. The oldest stand examined had the largest deviation from the site index curves (fig. 1). But even for this stand the maximum deviation was only 3 feet at age 86, and use of the site index curves would result in a maximum error of only 2 feet. The magnitude of these deviations is similar to the 1.4 foot maximum error noted by Lundgren and Dolid (1970) for their equations describing the site index curves.

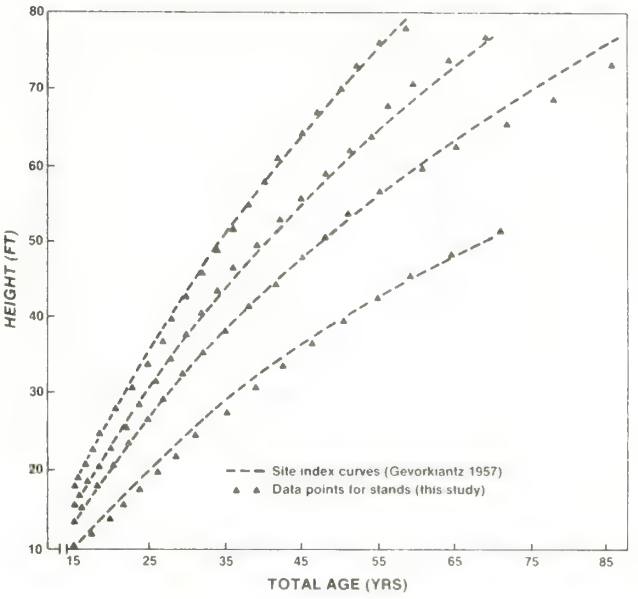

Figure 1.—*Height growth of four natural stands of red pine compared with site index curves.*

Some of the deviations noted in figure 1 are due to measurement errors and to short-term growth fluctuations caused by weather, insects, etc. To smooth out some of these variations, master site index curves were computed separately for natural stands and for planted stands using all the stands. The curve model (see Eq. 1) was that of Lundgren and Dolid (1970).

The coefficients for planted stands do not differ significantly from those for natural stands and neither differs from those of Lundgren and Dolid (table 2). Within the range of ages (15-70) and site indexes (40-75) the equations developed from planted or natural stands predict height closely to that from Lundgren and Dolid's equation: the maximum difference being 1.4 feet. Even when extended far beyond the range of the data to 100 years, the maximum difference was only 4 feet. Beyond age 100,

Table 2.—*Regression coefficients[1] for red pine height growth*

	Lundgren & Dolid (1970)	Alban & Prettyman (This study)	
		Natural stands	Planted stands
bo	1.956	1.913	1.800
b1	-2.176	-2.170	-2.046
b2	-0.0164	-0.0176	-0.0188

[1]Equation form:
Height = (site index) (bo + b1 e^{b2Age})

when polymorphism in height growth may be more common (Carmean 1975), we have no data. But the implications for forest management of height growth deviations from the site index curves beyond age 100 are minor, particularly under the more intensive management likely to be practiced in the future.

Clearly, height growth on the fine-textured soils of this study closely follows the site index curves beyond age 15. Because these stands represent both natural and planted stands, and a wide range of soil conditions and site quality, it appears that the standard site index curves are adequate for describing the height growth of red pine on well-drained, fine-textured soils.

B. Height growth of young stands

Even though height growth of red pine on fine-textured soils follows the appropriate site index curve beyond age 15 (fig. 1), large errors are possible when site index is estimated from young stands. This is so for two reasons: (1) early height growth is strongly influenced by many factors unrelated or weakly related to later growth, and (2) the site index curves were developed from trees 20 years and older and their extrapolation to younger ages is a possible source of error. Lundgren and Dolid (1970) attempted to extend the site index curves to younger ages by developing a more complex equation that goes through the origin (fig. 2):

$$\text{Height} = (\text{Site index})(1.89)(1-e^{-0.01979\ \text{Age}})^{1.3892}. \quad \text{(Eq. 2)}$$

At age 10 many of the stands in this study fell below the height predicted for a very poor site (fig. 2). In addition, the site index curves predict that height of dominants and codominants at age 10 will be greater than 10 feet for all stands with site index greater than 57 feet. We found no stands in this study taller than 10 feet at age 10 even when the attained site index was very high (fig. 2). Others who have done stem analysis of red pine trees also found that height at age 10 is seldom if ever over 10 feet. (Hannah 1967, Richards *et al.* 1962, Van Eck and Whiteside 1963). Thus the site index curves extended to young ages by Lundgren and Dolid's equation 2 are inaccurate and if site index is estimated from total height and total age, its value will vary greatly depending on the age of measurement (fig. 2).

This problem is not unique to red pine growth on fine-textured soils, but it is perhaps most serious on these sites because brush or grass competition is more intense than on sandier sites. Therefore the conclusion (Alban 1979) that site index curves are not an accurate way to estimate site index until age 25

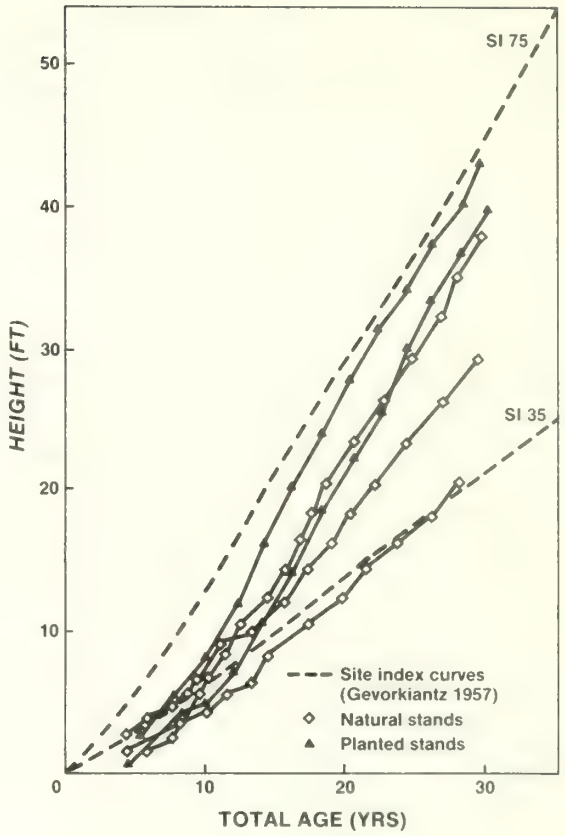

Figure 2.—*Early height growth of dominant and codominant red pine trees from two planted and three natural stands.*

appears particularly valid for red pine on fine-textured soils. However, site index at the younger ages can be estimated by the growth intercept method (Alban 1979) or by the use of soils (Carmean 1975) or habitat types (Kotar and Coffman 1982).

Even when site index curves are used for stands greater than age 25, significant errors can occur in estimating site index if early growth was greatly different from average. For example, plantation records plus ring counts and/or whorl measurements indicate that several planted stands in the current study took about 6 years from seed to attain a height of 6 inches. It is not known why this is so (no replanting was recorded), but the effect is to make the early growth of these stands indicate very poor site quality which is not reflected in later growth.

Early height growth of red pine on fine-textured soils is not closely related to site index (fig. 3) as was found earlier for red pine in general (Alban 1979). If early growth factors such as stock conditions, planting techniques, and plant competition can be controlled (Wittenkamp and Wilde 1964), or if sites can be stratified into habitat types (Kotar and Coffman 1982),

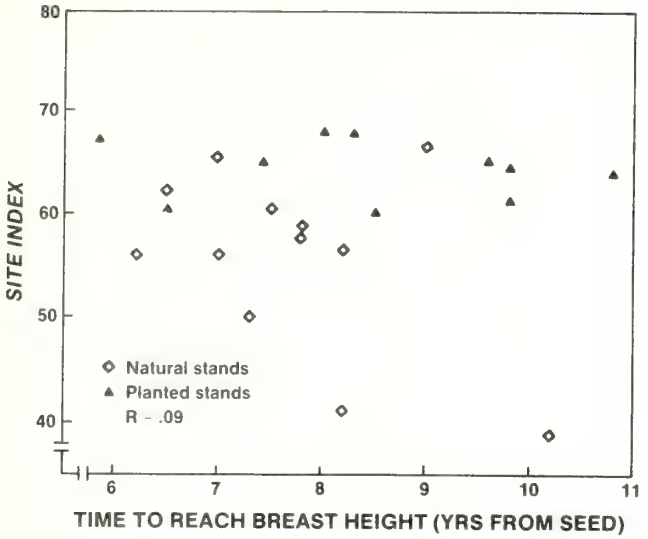

Figure 3.—*Affect of site index on the number of years for red pine trees to reach breast height.*

a relation between site quality and time required to reach breast height may be established. If so, it may be possible to extend the site index curves to younger ages and their usefulness would be greatly increased. However, at the present time the early height growth relations of red pine are poorly understood. And because of the extreme importance of weather conditions at the time of stand establishment, it is likely that the precision of the site index curves will continue to be lower at young ages than later in the life of the stand.

This early height growth should be taken into account when using the site index curves to estimate site index. It would seem prudent to calculate the years required to attain breast height and the growth intercept for each stand in which site index is estimated. These values should aid in interpreting the reasonableness of site index estimates made from the site index curves. For example, the current study as well as previous ones (Alban 1972) indicate that red pine takes about 8 years from seed to reach breast height irrespective of site. If stands take significantly longer than 8 years to reach breast height, total age can be adjusted accordingly and site index can be recalculated on this basis.

This is equivalent to using ring count at BH rather than total age, for site index determination (Husch 1956). In practice this is what is frequently done because total age is usually estimated by adding 8 years to ring count at breast height. As an example, one site of the current study took 5 years to reach a 6 inch height and 11 years to attain breast height. This slow early growth suggests a poorer site index than indicated by later growth, and the effect is most pronounced at the younger ages. Site indexes (Eq. 1) for this stand based on total height at total ages of 46, 30, and 20 years was 64.0, 58.5, and 52.6 feet, respectively. Recalculating site index based on an assumed 8 years to reach BH (i.e., subtracting 3 years from the three ages above) results in site index estimates of 67.7, 65.5, and 66.0 feet, respectively. The age-adjusted site index values are similar to those estimated by the growth intercept method 67.4 (Alban 1979) and are undoubtedly more realistic estimates of site index than those determined from total height and unadjusted age, particularly at the younger ages.

CONCLUSIONS

Red pine height growth on fine-textured, well-drained soils is accurately depicted by the Gevorkiantz site index curves beyond age 15. At younger ages the site index curves do not accurately describe red pine height growth. To confidently estimate a red pine stand site index from the site index curves the number of years to attain breast height should be determined. If this time is more than 2 or 3 years greater than the regionwide average of 8 years, an adjusted stand age will improve the accuracy of site index determinations.

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Research Paper **NC-250**

Tree Volume and Biomass Equations for the Lake States

Jerold T. Hahn

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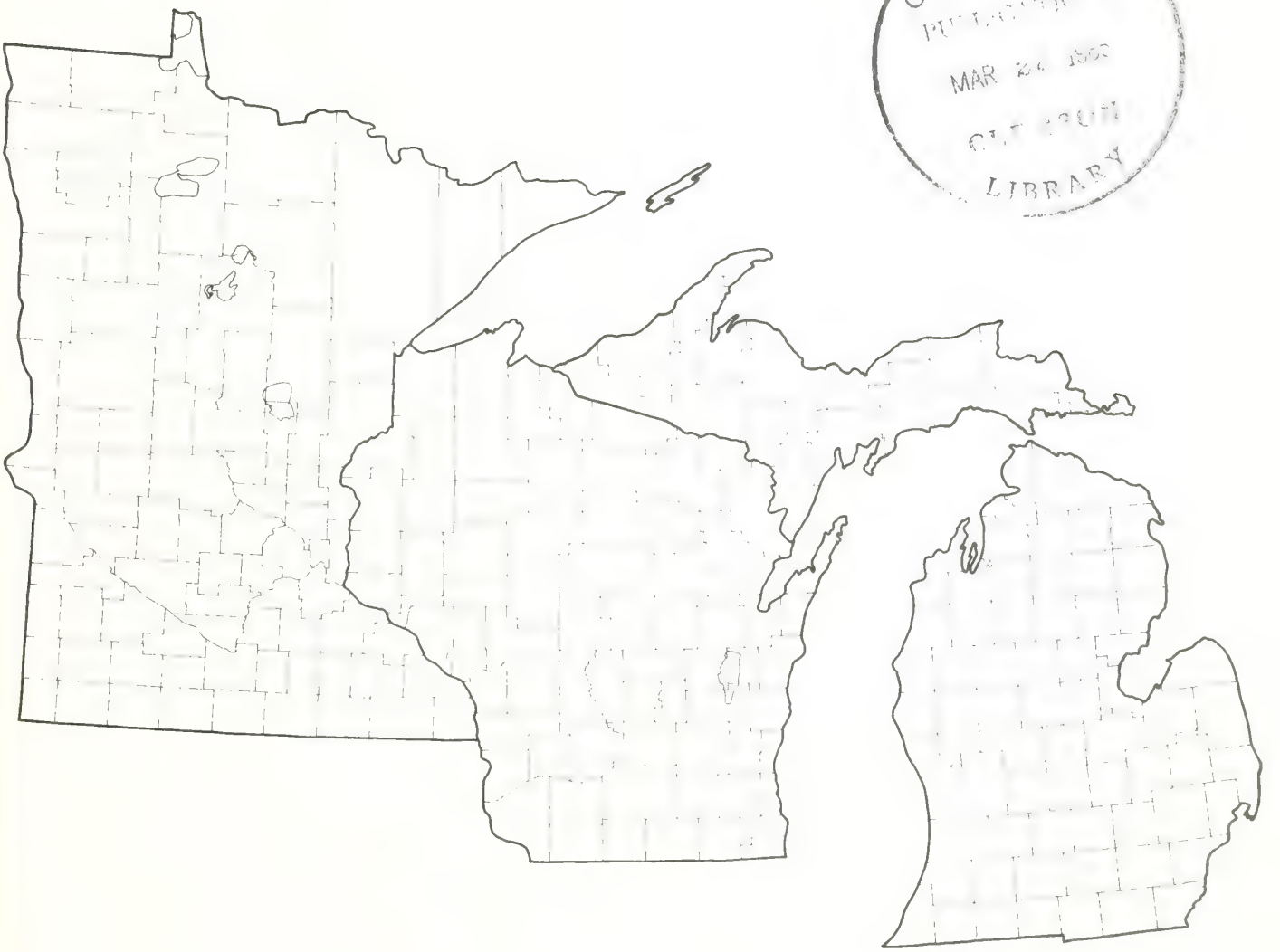

CONTENTS

	Page
How the equations were developed	1
How to compute volume	2
How to compute biomass in green tons	3
Literature cited	6
Appendix I	9
Appendix II	9
Appendix III	9
Appendix IV	10

Hahn, Jerold T.
Tree volume and biomass equations for the Lake States. Res. Pap. NC-250. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 10 p.

Presents species specific equations and methods for computing tree height, cubic foot and board foot volume, and biomass for the Lake States (Michigan, Minnesota, and Wisconsin). Height equations compute either total or merchantable height to a variable top d.o.b. from d.b.h., site index, and basal area. Volumes and biomass are computed from d.b.h. and height.

KEY WORDS: Inventory, computer, height, cull, cubic foot, board foot, green tons.

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1992 Folwell Avenue
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September 1984

TREE VOLUME AND BIOMASS EQUATIONS FOR THE LAKE STATES

Jerold T. Hahn, *Principal Mensurationist*

This paper presents volume and biomass equations for individual trees in the Lake States of Michigan, Wisconsin, and Minnesota. Equations and computation procedures are for:

gross cubic foot volume,
net cubic foot volume,
gross board foot volume (International ¼-inch rule),
net board foot volume (International ¼-inch rule), and
above ground biomass (green tons).

The Forest Inventory and Analysis (FIA) research work unit at the North Central Forest Experiment Station uses these equations to compute volume and biomass of sample trees to compile volume and growth estimates for State inventories. These equations are used in the current (1983) Wisconsin forest inventory. They are also included in the computerized data bases the FIA Unit has compiled for the Lake States (Hahn and Hansen in prep.). These equations could also be used by those needing similar volume-per-tree estimates.

Separate equations for major species and species groups of the region are presented as well as separate equations for growing-stock and cull trees (see Appendixes II and III for definitions and for species and species groups). Also included are the equations for merchantable and total tree height from Ek *et al.* (1981), for computing the volume of a 1 foot stump from Raile (1982), and for computing bark volume.

Data needed to compute volume and biomass are species, diameter at breast height (d.b.h.), and merchantable height. If height is not measured, merchantable height can be estimated from d.b.h., species site index, stand basal area, and diameter at the limit of merchantability (top diameter outside bark (top d.o.b.)).[1]

The volume equations assume a 4 inch top d.o.b. for cubic foot volume and a 7 (softwoods) or 9 (hardwoods) inch top d.o.b. for board foot volume. If species site index is not available, it can be computed using the equations and methods presented by Carmean *et al.* (in press) or stand site index may be used.

HOW THE EQUATIONS WERE DEVELOPED

Tree Volume Computation

Local net volume equations have been derived as a part of the forest inventories of Wisconsin (Hahn 1973), Minnesota (Raile 1981), and Michigan (Raile *et al.* 1982). The data files created in conjunction with the derivation of these equations serve as a data base for developing regional equations. This data base is comprised of field data collected on 101,642 trees measured during the most recent inventories of Wisconsin (1968), Minnesota (1977), and Michigan (1981). Data included are tree d.b.h., merchantable height, top d.o.b., species site index, species, tree class, and stand basal area (all trees 1 inch d.b.h. and larger). For sawtimber-size trees, measurements were taken at both the sawtimber and poletimber limits of merchantability. Field crews also estimated cull volume (both board foot and cubic foot) in each tree (see Appendix IV for the cull estimation procedure). The availability of regional height equations permitted the use of height estimates as an independent variable in the volume model (Ek *et al.* 1981). These height equations are included in this paper for the convenience of the reader.

Equations developed by Robert N. Stone and the author (see Appendix I) based on Gevorkiantz and Olsen's (1955) composite volume tables for the Lake States were used to estimate the cubic foot volume in

[1] *The poletimber merchantability limits include trees greater than or equal to 5.0 inches d.b.h. from a 1.0 foot stump to a 4.0 inch minimum top d.o.b. or to the point where the central stem breaks into limbs. Dimensions for sawtimber are d.b.h. greater than or equal to 9.0 inches to a 7.0 inch minimum top d.o.b. for softwoods and d.b.h. greater than or equal to 11.0 inches to a 9.0 inch minimum top d.o.b. for hardwoods or to the point where the central stem breaks into limbs (U.S. Department of Agriculture 1975).*

each tree and board foot volume in sawtimber-sized trees. These equations estimate tree volume inside bark from a 1 foot stump to the merchantable limit based on three measurements: d.b.h., merchantable height, and top d.o.b. This estimated volume was then corrected for species differences in bark thickness using equations developed for the region from felled tree measurements to arrive at adjusted gross volume. In addition, tree height to a 4 inch top d.o.b. for all trees and tree height to a 7 (softwoods) or 9 (hardwoods) inch top d.o.b. for sawtimber-size trees were computed as were tree heights to the observed top diameters if the diameters were greater than 4, 7, or 9 inches, respectively. The volume of the section between the observed top and the standard top was computed using Smailian's formula for short sections and added to both the above adjusted gross volume and the field estimated cull volume. The result of this process provided the dependent variable volume for each tree. The species specific volume equations developed are described in the next section.

Volume Estimation Equations

The common volume model—

$$V = b_0 + b_1 D^2 H \qquad (1)$$

where:

D = diameter breast height (d.b.h.) in inches,

H = merchantable height in feet,

V = gross volume in cubic feet,

and b_0 and b_1 are appropriate regression coefficients—was found to describe the data well and was chosen for this study.

Species specific equation coefficients were derived for cubic foot and board foot (International ¼-inch rule) volumes computed as described in the previous section for merchantable height to 4, 7, or 9 inch top d.o.b. as appropriate. Cull percentages (based on the individual tree estimates made in the field) were then developed for growing stock (desirable and acceptable trees), rough and short-log, and rotten tree classes (see Appendix II for definitions). Coefficients were computed for most of the species groups recognized by Forest Inventory and Analysis. Some grouping was necessary when data were insufficient for a viable regression analysis. Species for which no data were available were assigned coefficients on the basis of typical bole form (see Appendix III for species and species groups).

The FIA Unit divides inventoried States into geographical subunits based on similarity of forest types and economic/political boundaries—Michigan and Minnesota each have four units and Wisconsin has five (fig. 1). The influence of geographical location was investigated by regression analysis using dummy variables for unit effects. The F statistic showed no significant contribution to the gross volume equation by geographical unit.

The coefficients of model (1) were estimated by regression analysis using the Statistical Package for the Social Sciences package of statistical routines (tables 2 and 3).

HOW TO COMPUTE VOLUME

1. If an observed merchantable height is not available, compute merchantable height to the appropriate top d.o.b. (4 inches for cubic foot volume or biomass, 7 (softwood) or 9 (hardwood) inches for board foot volume) using the appropriate species group coefficients (b) from table 1 and the following equation from Ek *et al.* (1981).

$$\text{Height} = 4.5 + b_1 (1-e^{(b_2 D)})^{b_3} \cdot S^{b_4} \cdot T^{b_5} \cdot B^{b_6} \qquad (2)$$

where:

Height = tree height (merchantable or total),

D = diameter breast height (d.b.h.),

e = base of natural logarithm,

S = site index (species specific if possible),

T = (1.00001 -d/D), d = top d.o.b., a value of 0.0 gives total height, and

B = stand basal area.

For example, a 12 inch d.b.h. sugar maple to a 4 inch top d.o.b. in a stand with a site index of 65 feet and basal area 88 square feet will have a height of:

$$\text{Height} = 4.5 + 5.3416(1-e^{(-0.23044 \cdot 12.0)})^{1.1529} \cdot 65^{0.54194} \cdot (1.00001 - 4.0/12.0)^{0.83440} \cdot 88^{0.06372}$$

$$= 49.6 \text{ feet.}$$

2. Solve equation (1) to obtain gross volume and subtract the cull percentage to obtain net volume using the appropriate species coefficients and percentage from table 2 or 3 depending on type of volume desired. From model (1) the above tree has a gross cubic foot volume of:

$$\text{Gross volume} = 1.3746 + 0.002206(12.0)^2 \cdot 49.6$$
$$= 17.1 \text{ cubic feet}$$

and if it is a growing-stock tree, it has a net cubic foot volume of:

Net volume = 17.1 (1.0 - 0.063) = 16.0 cubic feet.

If board foot volume is desired, it is also determined from model (1) but use coefficients from table 3 and saw log merchantability limits as follows:

Height = $4.5 + 5.3416\,(1\text{-}e^{(-0.23044 \cdot 12.0)})^{1.1529} \cdot 65^{0.54194} \cdot (1.00001 - 9.0/12.0)^{0.83440} \cdot 88^{0.06372}$
= 24.4 feet;
Gross volume = $36.859 + 0.01534\,(12.00)^2 \cdot 24.4$
= 90.8 board feet; and
Net volume = 90.8 (1.0 - 0.156) = 76.6 board feet.

HOW TO COMPUTE BIOMASS IN GREEN TONS

Biomass is computed using two systems—one for trees 5 inches d.b.h. and larger and the other for trees less than 5 inches d.b.h.

A. *Trees 5 inches d.b.h. or larger*

1. Compute gross cubic foot volume as above.
2. Compute volume inside bark of a 1 foot stump using appropriate stump volume species coefficient from column 1 of table 4 and the equation:

$$\text{Stump volume } (ft^3) = S \cdot D^2. \quad (3)$$

3. Compute Species Correction Factor (SCF) for bark differences using appropriate species coefficients from columns 2 and 3 of table 4 and the equation:

$$SCF = (b_0 + b_1 \cdot D)/100. \quad (4)$$

4. Compute bole bark weight using the equation:

$$\text{Bark (lbs)} = (\text{gross cubic volume} + \text{stump volume}) \cdot (1.1646\text{-}SCF) \cdot 37. \quad (5)$$

5. Compute merchantable bole green weight using appropriate species weight (WT) from column 5 of table 4 and the equation:

$$\text{Bole biomass (tons)} = (\text{bark} + (\text{gross cubic volume} + \text{stump volume}) \cdot WT)/2{,}000. \quad (6)$$

6. Compute weight of top (section above merchantable portion of tree) and limbs using the equation:

$$\text{top biomass (tons)} = 0.4545 \cdot (\text{bark} + \text{gross volume} \cdot WT)/2{,}000. \quad (7)$$

7. Add bole weight to top weight for total biomass in green tons.

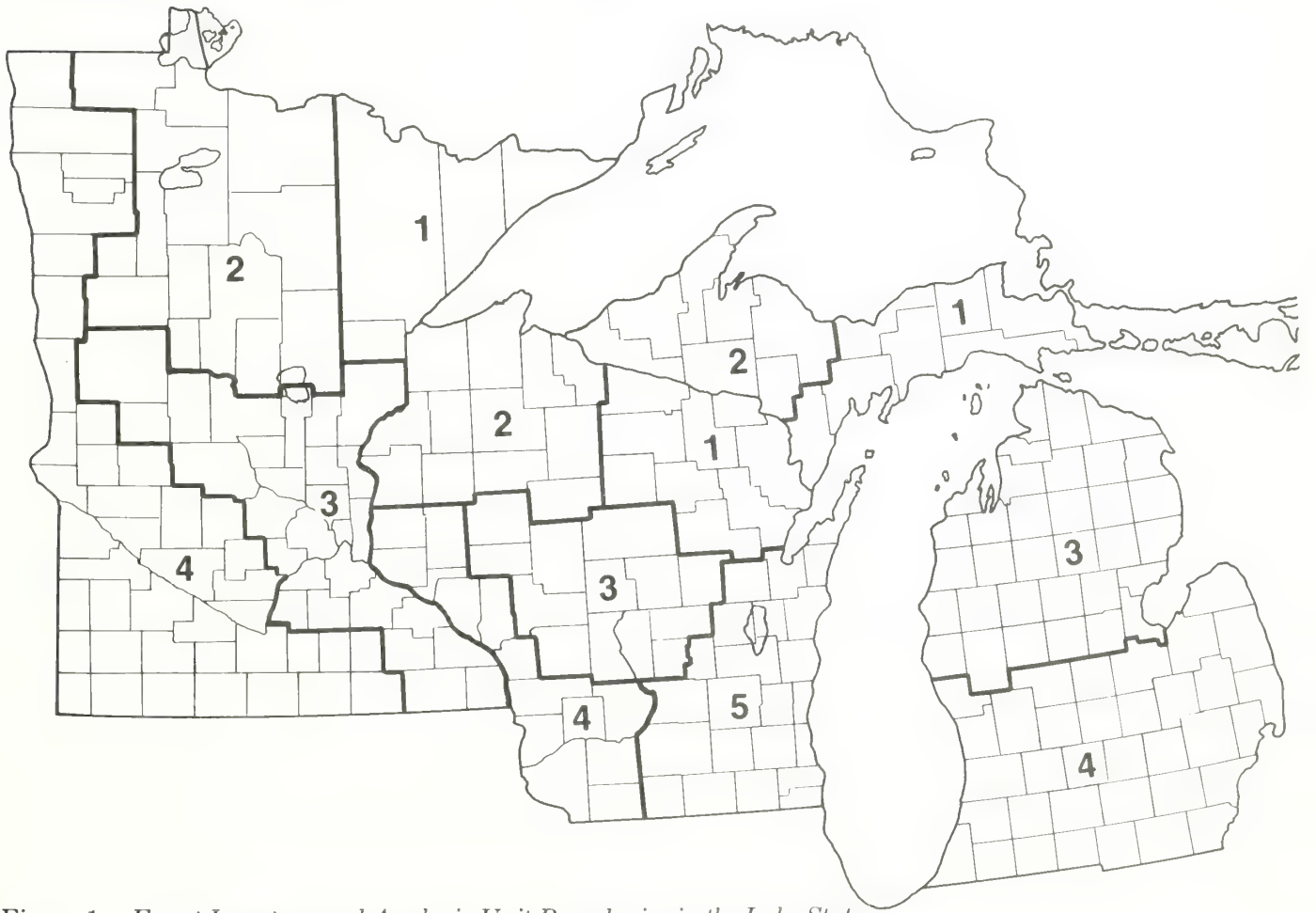

Figure 1.—*Forest Inventory and Analysis Unit Boundaries in the Lake States.*

Table 1.—*Coefficients and standard errors of height equations for model 2*[1]

Species group	Coefficient						Standard error
	b_1	b_2	b_3	b_4	b_5	b_6	
Jack pine	16.9340	0.12972	1.0000	0.20854	0.77792	0.12902	7.2
Red pine	36.8510	.08298	1.0000	.00001	.63884	.18231	8.5
White pine	16.2810	.08621	1.0000	.16220	.86833	.23316	10.7
Ponderosa pine	36.8510	.08298	1.0000	.00001	.63884	.18231	([2])
White spruce	31.9570	.18511	1.7020	0	.68967	.16200	8.2
Black spruce	20.0380	.18981	1.2909	.17836	.57343	.10159	5.5
Balsam fir	14.3040	.19894	1.4195	.23349	.76878	.12399	5.9
Hemlock	5.3117	.10357	1.0000	.68454	.71410	0	7.2
Tamarack	13.6200	.24255	1.2885	.25831	.68128	.10771	5.6
Eastern redcedar	8.2079	.19672	1.3112	.33978	.76173	.11666	([3])
Northern white-cedar	8.2079	.19672	1.3112	.33978	.76173	.11666	5.4
Other softwoods	16.9340	.12972	1.0000	.20854	.77792	.12902	([4])
Select white oak	9.2078	.22208	1.0000	.31723	.82560	.13465	8.2
Select red oak	6.6844	.19049	1.0000	.43972	.82962	.10806	8.2
Other red oak	3.8011	.39213	2.9053	.55634	.84317	.09593	7.7
Select hickory	6.1034	.17368	1.0000	.44725	1.02370	.14610	7.3
Other hickory	6.1034	.17368	1.0000	.44725	1.02370	.14610	7.3
Basswood	6.3628	.27859	1.8677	.49589	.76169	.05841	7.7
Beech	7.1852	.28384	1.4417	.38884	.82157	.11411	([5])
Yellow birch	7.1852	.28384	1.4417	.38884	.82157	.11411	9.3
Hard maple	5.3416	.23044	1.1529	.54194	.83440	.06372	7.7
Soft maple	6.8600	.27725	1.4287	.40115	.85299	.12403	7.2
Elm	8.4580	.27527	1.9602	.34894	.89213	.12594	8.1
Black ash	11.2910	.25250	1.5466	.35711	.75060	.06859	7.2
White & green ash	8.1782	.27316	1.7250	.38694	.75822	.10847	8.3
Sycamore	6.3628	.27859	1.8677	.49589	.76169	.05841	([6])
Cottonwood	13.6250	.28668	1.6124	.30651	1.02920	.07460	8.1
Willow	13.6250	.28668	1.6124	.30651	1.02920	.07460	([7])
Hackberry	6.8600	.27725	1.4287	.40115	.85299	.12403	([8])
Balsam poplar	6.4301	.23545	1.3380	.47370	.73385	.08228	6.7
Bigtooth aspen	5.5346	.22637	1.0000	.46918	.72456	.11782	7.2
Quaking aspen	6.4301	.23545	1.3380	.47370	.73385	.08228	6.7
Paper birch	7.2773	.22721	1.0000	.41179	.76498	.11046	7.1
River birch	7.2773	.22721	1.0000	.41179	.76498	.11046	([9])
Sweetgum	5.3416	.23044	1.1529	.54194	.83440	.06372	([10])
Tupelo	5.3416	.23044	1.1529	.54194	.83440	.06372	([10])
Black cherry	5.3416	.23044	1.1529	.54194	.83440	.06372	([10])
Black walnut	6.3628	.27859	1.8677	.49589	.76169	.05841	([6])
Butternut	6.3628	.27859	1.8677	.49589	.76169	.05841	([6])
Yellow poplar	6.3628	.27859	1.8677	.49589	.76169	.05841	([6])
Other hardwoods	6.9572	.26564	1.0000	.48660	.76954	.01618	([11])
Noncommercial spp.	6.9572	.26564	1.0000	.48660	.76954	.01618	([11])

[1]From Ek *et al.*, 1981
[2]No data available. Red pine equation used.
[3]No data available. Northern white-cedar used.
[4]No data available. Jack pine used.
[5]No data available. Yellow birch used.
[6]No data available. Basswood used.
[7]No data available. Cottonwood used.
[8]No data available. Soft maple used.
[9]No data available. Paper birch used.
[10]No data available. Hard maple used.
[11]No data available. Silver maple used.

Table 2.—*Cubic foot volume regression coefficients, standard errors, and coefficients of determination for model 1 and percent cull for three tree classes*

Species group	Trees	Coefficients		Standard error	R^2	Percent cull by tree class		
		b_0	b_1			Growing stock	Rough	Rotten
	Number			*Feet*[3]				
Jack pine	1,671	1.2446	0.002165	1.70	0.93	2.6	17.8	63.1
Red pine	1,005	2.0822	.002046	4.09	.93	1.3	11.2	74.3
White pine	1,952	0	.002364	13.21	.96	3.2	16.6	64.6
Ponderosa pine	[1]—	2.0822	.002046	—	—	1.3	11.2	74.3
White spruce	1,030	.3365	.002599	4.57	.93	1.6	11.7	56.0
Black spruce	1,338	.2631	.002706	1.70	.90	1.4	12.1	57.7
Balsam fir	2,752	.2514	.002679	1.82	.93	2.1	11.1	63.4
Hemlock	1,368	0	.001856	9.75	.89	5.4	24.9	71.9
Tamarack	1,591	1.4109	.002227	1.65	.89	2.7	16.8	58.4
Eastern redcedar	[2]43	.5905	.002168	1.47	.94	3.4	22.0	52.2
Northern white-cedar	3,124	1.0406	.002408	3.42	.87	3.8	17.2	61.2
Other softwoods	[2]151	.5905	.002168	1.47	.94	3.4	22.0	52.2
Select white oak	2,081	.7316	.001951	6.31	.92	5.5	14.0	65.6
Select red oak	3,401	1.6378	.002032	5.91	.92	5.3	14.4	63.6
Other red oak	2,463	.7554	.002174	14.36	.57	6.1	10.7	66.5
Select hickory	[3]264	2.4364	.001881	3.59	.91	4.7	15.2	65.7
Other hickory	[3]224	2.4364	.001881	3.59	.91	4.7	15.2	65.7
Basswood	1,763	.9239	.002206	5.16	.95	4.4	14.0	63.3
Beech	627	2.2793	.002395	8.15	.90	8.1	21.8	55.3
Yellow birch	1,566	0	.002480	14.39	.88	8.9	19.7	64.0
Hard maple	3,780	1.3746	.002206	6.72	.90	6.3	17.7	61.7
Soft maple	3,173	1.7283	.002189	9.80	.87	5.8	16.8	62.3
Elm	[4]3,692	0	.002325	11.42	.91	6.3	13.2	64.0
Black ash	1,256	2.5990	.001792	3.23	.93	5.3	20.2	67.2
White & green ash	1,516	1.5280	.002021	6.84	.91	4.6	17.8	62.2
Sycamore	[5]21	0	.002485	28.13	.90	5.5	19.7	70.6
Cottonwood	[5]173	0	.002485	28.13	.90	5.5	19.7	70.6
Willow	[5]161	0	.002485	28.13	.90	5.5	19.7	70.6
Hackberry	[4]31	0	.002325	11.42	.91	6.3	13.2	64.0
Balsam poplar	2,631	0	.002335	6.15	.87	4.5	19.0	65.2
Bigtooth aspen	3,398	.9461	.002247	13.37	.42	4.4	20.7	59.7
Quaking aspen	2,419	2.0756	.001913	4.08	.81	5.2	21.8	61.8
Paper birch	3,760	2.3037	.001810	3.22	.79	4.5	14.3	64.9
River birch	[5]43	0	.002485	28.13	.90	5.5	19.7	70.6
Sweetgum	[6]—	0	.002485	—	—	5.5	19.7	70.6
Tupelo	[6]—	0	.002485	—	—	5.5	19.7	70.6
Black cherry	[7]821	2.6341	.001887	5.86	.88	6.8	15.5	61.2
Black walnut	[7]85	2.6341	.001887	5.86	.88	6.8	15.5	61.2
Butternut	[7]160	2.6341	.001887	5.86	.88	6.8	15.5	61.2
Yellow poplar	[7]35	2.6341	.001887	5.86	.88	6.8	15.5	61.2
Other hardwoods	290	1.4824	.001796	4.82	.86	8.7	21.0	64.2
Noncommercial spp.	393	.8670	.001940	2.30	.86	8.7	16.8	64.2

[1]No data available, red pine equation used.
[2]Eastern redcedar and other softwoods data combined.
[3]Select and other hickory data combined
[4]Elm and hackberry data combined
[5]Sycamore, cottonwood, willow and river birch data combined
[6]No data available, river birch equation used.
[7]Black cherry, black walnut, butternut and yellow poplar data combined.

Table 3.—*Board foot volume regression coefficients, standard errors, and coefficients of determination for model 1 and percent cull for two tree classes*

Species group	Trees	Coefficients		Standard error	R^2	Percent cull by tree class	
		b_0	b_1			Growing stock	Short log
	Number			*Board feet*			
Jack pine	1,184	19.149	0.01307	14.84	0.85	4.6	46.2
Red pine	1,231	24.848	.01298	28.38	.90	2.9	38.2
White pine	1,511	0	.01625	89.30	.90	5.6	46.6
Ponderosa pine	[1]—	24.848	.01298	—	—	2.9	38.2
White spruce	608	6.810	.01611	34.73	.90	3.1	20.6
Black spruce	342	0	.01735	20.11	.95	2.9	47.3
Balsam fir	1,231	4.658	.01694	17.81	.85	4.7	50.1
Hemlock	989	0	.01054	68.62	.94	8.1	59.4
Tamarack	311	17.592	.01427	14.49	.79	5.0	35.7
Eastern redcedar	[2]32	17.167	.01404	15.88	.81	5.2	31.3
Northern white-cedar	2,117	12.532	.01560	17.81	.90	7.4	45.8
Other softwoods	[2]32	17.167	.01404	15.88	.81	5.2	31.3
Select white oak	1,669	46.038	.01173	38.58	.93	16.9	60.6
Select red oak	3,224	41.410	.01326	39.99	.91	15.6	65.4
Other red oak	782	34.677	.01370	41.93	.86	16.1	62.2
Select hickory	[3]91	57.449	.01122	28.33	.88	11.3	58.3
Other hickory	[3]53	57.449	.01122	28.33	.88	11.3	58.3
Basswood	1,310	36.821	.01435	41.61	.90	15.2	66.5
Beech	296	56.500	.01465	53.84	.86	14.6	62.2
Yellow birch	631	14.575	.01766	77.04	.84	15.9	63.6
Hard maple	2,563	36.859	.01534	55.67	.87	15.6	64.4
Soft maple	1,788	63.992	.01215	61.83	.89	15.9	59.7
Elm	[4]1,639	28.875	.01466	67.68	.89	17.8	57.0
Black ash	457	70.167	.01015	30.62	.92	15.0	65.0
White & green ash	536	65.124	.01124	71.73	.81	15.8	66.6
Sycamore	[5]12	34.832	.01458	189.95	.83	13.6	47.3
Cottonwood	[5]140	34.832	.01458	189.95	.83	13.6	47.3
Willow	[5]89	34.832	.01458	189.95	.83	13.6	47.3
Hackberry	[4]12	28.875	.01466	67.68	.89	17.8	57.0
Balsam poplar	795	17.978	.01578	32.70	.93	16.9	62.8
Bigtooth aspen	932	31.842	.01483	18.23	.94	15.1	75.5
Quaking aspen	2,080	29.329	.01480	16.98	.93	16.4	68.9
Paper birch	981	37.619	.01404	19.45	.87	18.2	61.2
River birch	[5]10	34.832	.01458	189.95	.83	13.6	47.3
Sweetgum	[6]—	34.832	.01458	—	—	13.6	47.3
Tupelo	[6]—	34.832	.01458	—	—	13.6	47.3
Black cherry	[7]173	67.801	.01109	57.97	.76	16.0	62.8
Black walnut	[7]51	67.801	.01109	57.97	.76	16.0	62.8
Butternut	[7]34	67.801	.01109	57.97	.76	16.0	62.8
Yellow poplar	[7]30	67.801	.01109	57.97	.76	16.0	62.8
Other hardwoods	45	36.341	.01339	25.07	.88	19.4	55.3
Noncommercial spp.	[8]—	36.341	.01339	—	—	19.4	55.3

[1]No data available, red pine equation used.
[2]Eastern redcedar and other softwoods data combined.
[3]Select and other hickory data combined
[4]Elm and hackberry data combined.
[5]Sycamore, cottonwood, willow, and river birch data combined.
[6]No data available, river birch equation used.
[7]Black cherry, black walnut, butternut, and yellow poplar data combined
[8]No data available, other hardwoods equation used.

Table 4.—*Coefficients for stump volume, bark corrections, and biomass*

Species group	Stump coef.	Bark correction coef.		Biomass[1]
		b_0	b_1	lbs/ft^3
Jack pine	0.007017	91.227	0.325	50
Red pine	.007176	90.365	.325	42
White pine	.008269	88.582	.325	36
Ponderosa pine	.007176	90.365	.325	42
White spruce	.010699	99.669	.325	35
Black spruce	.008877	100.100	.325	32
Balsam fir	.009967	97.520	.325	45
Hemlock	.008579	88.582	.325	50
Tamarack	.008877	102.560	.325	47
Eastern redcedar	.008877	100.080	.325	28
Northern white-cedar	.011946	100.080	.325	28
Other softwoods	.008877	91.227	.325	43
Select white oak	.009727	87.433	.325	62
Select red oak	.008908	90.051	.325	62
Other red oak	.008980	89.543	.325	63
Select hickory	.008980	85.094	.597	63
Other hickory	.008980	85.094	.597	63
Basswood	.009639	88.054	.325	43
Beech	.010202	94.853	.325	50
Yellow birch	.009968	92.943	.325	57
Hard maple	.008894	93.164	.325	56
Soft maple	.008476	94.853	.325	48
Elm	.010422	91.894	.325	54
Black ash	.011016	91.834	.325	49
White & green ash	.008728	91.834	.325	49
Sycamore	.008980	89.579	.325	50
Cottonwood	.011145	91.894	.325	54
Willow	.011145	91.894	.325	54
Hackberry	.010422	91.894	.325	54
Balsam poplar	.006594	89.579	.325	40
Bigtooth aspen	.006594	89.579	.325	43
Quaking aspen	.007369	92.838	.325	43
Paper birch	.008380	97.285	.325	50
River birch	.008380	97.285	.325	50
Sweetgum	.008980	89.579	.325	50
Tupelo	.008980	89.579	.325	50
Black cherry	.008980	88.688	.325	52
Black walnut	.008980	88.688	.325	52
Butternut	.008980	88.688	.325	52
Yellow poplar	.008980	88.688	.325	52
Other hardwoods	.008980	89.579	.325	50
Noncommercial spp.	.008980	89.579	.325	50

[1]Green wt/ft^3 from Markwardt 1930.

B. *Trees less than 5 inches d.b.h.*

For trees less than 5 inches d.b.h. the following green weight equation can be used.[2]

Total biomass (tons) = $(4.8900625 \cdot D^{2.4323866}) \cdot 0.8/2{,}000$

where biomass is in green tons and D is d.b.h. (inches).

Continuing the above example:

Stump volume = $0.008894 \cdot 12^2 = 1.2807$ cubic feet

SCF = $(93.164 + 0.325 \cdot 12)/100 = 0.97064$

Bark = $(17.1 + 1.2807) \cdot (1.1646 - 0.97064) \cdot 37$
= 131.91 lbs

Bole weight = $(131.91 + (7.1 + 1.2807) \cdot 56)/2{,}000$
= 581 tons

Top weight = $0.4545 \cdot (131.91 + 17.1 \cdot 56)/2{,}000$
= 248 tons

Total biomass = 581 + 248 = 829 tons.

Cubic foot volume in the saw log portion of the tree can be computed using the saw log merchantable height and coefficients from table 2 or

Gross volume = $1.3746 + 0.002206 \cdot 12^2 \cdot 24.4$
= 9.1 cubic feet

Net volume = 9.1 (1 - 0.063) = 8.5 cubic feet

The example tree is computed to have a merchantable height of 49.6 feet, gross volume of 17.1 cubic feet, net volume of 16 cubic feet, and above ground biomass of 0.829 green tons. The saw log portion of the tree contains gross volume of 90.8 board feet (9.1 cubic feet) and a net volume of 76.6 board feet (8.5 cubic feet).

The above data can be used to obtain a breakdown by tree component for the example tree (table 5).

Table 5.—*Volume and biomass by tree component*

Tree component	Volume		Biomass	
	Ft³	*Percent*	*Green tons*	*Percent*
Bole (gross)				
Saw log portion	9.1	29	0.254	31
Upper stem	8.0	25	0.225	27
Top and limbs	7.8	25	[1]0.218	26
Bark	5.2	17	0.096	12
Stump	1.3	4	0.036	4
Total	31.4	100	0.829	100

[1]The biomass in bole and tops and limbs does not include bark.

[2]*Equation developed by Gerhard K. Raile (personal communication 1982) using data from Young* et al. *(1976).*

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APPENDIX I
Tree Volume Equations

Stone's cubic foot volume equation uses diameter at breast height (D), merchantable height (H), and diameter outside bark at merchantable height (T) to estimate cubic foot volume inside bark (CV) from a 1 foot stump to the merchantable top as:

$CV = (3.0086 \times 10^{-3} + S1 + S2 + S3 + S4 + S5 + S6 + S7 + S8) \cdot 79.0$

where

$S1 = (2.0355 \times 10^{-3})D$
$S2 = (-3.0018 \times 10^{-3})T$
$S3 = (6.2381 \times 10^{-5})D^2$
$S4 = (2.5705 \times 10^{-5})D^2 \cdot H$
$S5 = (-7.0090 \times 10^{-6})H^2$
$S6 = (3.6708 \times 10^{-5})H \cdot T^2$
$S7 = (8.1400 \times 10^{-10})D2 \cdot H^3$
$S8 = (-1.90000 \times 10^{-9})D^2 \cdot H^2 \cdot T$

The board foot volume equation developed by Hahn using Stone's original data is:

$BV = 17.7488 + 7.3846 \cdot CV - 2.3523 \cdot D - 0.89945 \cdot H + 2.0726 \cdot T$

where

BV = board foot volume (International ¼-inch rule).

APPENDIX II
Metric Equivalents

1,000 board feet (International ¼-inch log rule) = 3.48 cubic meters.

Breast height = 1.37 meters above the ground.

1 cubic foot = 0.0283 cubic meter.

1 foot = 0.3048 meter.

1 inch = 2.54 centimeters.

Definition of Terms

Desirable trees.—Live trees having no serious defects that limit present or prospective use. Trees have relatively high vigor and have no visible signs of pathogens that may kill or seriously deteriorate them before rotation age. They would be favored by forest managers in silvicultural operations.

Acceptable trees.—Live trees having no serious defects that limit present or prospective use but that have pathogens or damage that may affect quality.

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees. (Note: excludes rough, rotten, and short-log trees.)

Rough trees.—Live trees that do not contain at least one merchantable 12-foot log, now or prospectively, because of roughness, poor form, or noncommercial species.

Rotten trees.—"Rough" trees in which more than 50 percent of the cull volume is rotten.

Short-log trees.—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

APPENDIX III
Species Groups and Species for Lake States Trees

Species group	Scientific names of included species
SOFTWOODS	
Jack pine	*Pinus banksiana*
Red pine	*Pinus resinosa*
White pine	*Pinus strobus*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Balsam fir	*Abies balsamea* var. *balsamea*
Hemlock	*Tsuga canadensis*
Tamarack	*Larix laricina*
Northern white-cedar	*Thuja occidentalis*
Other softwoods	*Pinus sylvestris*
	Pinus nigra
	Juniperus virginiana
	Larix decidua
	Picea abies
	Pseudotsuga menziesii
HARDWOODS	
White oak	*Quercus alba*
	Quercus bicolor
	Quercus macrocarpa
	Quercus muehlenbergii
Red oak	*Quercus rubra*
	Quercus velutina
	Quercus palustris
	Quercus ellipsoidalis
Hickory	*Carya cordiformis*
	Carya ovata
	Carya glabra

Basswood	*Tilia americana*
Beech	*Fagus grandifolia*
Yellow birch	*Betula alleghaniensis*
Hard maple	*Acer nigrum*
	Acer saccharum
Soft maple	*Acer rubrum* var. *rubrum*
	Acer saccharum
Elm	*Ulmus americana*
	Ulmus rubra
	Ulmus thomasii
Ash	*Fraxinus americana*
	Fraxinus nigra
	Fraxinus pennsylvanica
Cottonwood	*Populus deltoides*
Balsam poplar	*Populus balsamifera*
Paper birch	*Betula papyrifera*
	var. *papyrifera*
Aspen	*Populus grandidentata*
	Populus tremuloides
Black cherry	*Prunus serotina*
Other hardwoods	*Acer negundo*
	Betula nigra
	Celtis occidentalis
	Juglans cinerea
	Juglans nigra
	Salix nigra
	Liriodendron tulipifera
Noncommercial species	*Acer pensylvanicum*
	Acer spicatum
	Adanthus altessimor
	Corpinius carolinian
	Ostrya virginiana
	Circus canadensis
	Crataegus spp.
	Prunus pensylvanica
	Prunus virginiana
	Sorbus americana

APPENDIX IV
Cubic-Foot Cull[3]

For growing-stock, live and dead trees, cubic-foot cull is the cubic-foot volume of decayed or missing wood in merchantable sections and the total cubic-foot volume in sections that do not meet pulpwood specifications up to the growing stock top. A section meets pulpwood specifications unless:

1. It is less than 4 feet long.
2. It has a diameter less than 4 inches outside bark.
3. It is a fork.
4. A limb has a knot collar greater than the stem diameter at that point, or several limbs more than 2 inches d.o.b. within a 1-foot span have an aggregate knot collar diameter greater than the stem d.o.b. of the section.
5. A 4-foot section of bole is so crooked that a line drawn between the center of the ends falls outside the bark at any point.
6. A rotten section is unusable for industrial products. Regional standards are a 4-foot section less than 50 percent sound.

For short-log, rough, and rotten class live trees, or dead trees that were cull trees at time of death, record only the volume of decayed or missing wood up to the bole length top.

Compute cubic foot cull by determining the length of the section affected and the midpoint d.o.b. Then look up the volume of the section in a "Cubic Foot Volumes of Short Logs" table and record to the last 1/10 cubic foot.

Board Foot Cull[3]

Board-foot cull is the volume within the saw log portion of trees that cannot be recovered for use as lumber because of rot, sweep, crook, forks, or other defects.

Cull volumes include:

1. The entire volumes of tree sections that do not meet minimum log grade requirements.
2. The entire volume in any foot or longer section of a tree that is less than 50 percent sound.
3. The cull volume *only*, in any 1-foot or longer section of a tree that is greater than 50 percent sound.
4. Computed volumes for sweep and crook.
5. Forks or stoppers (any limb or group of 2 inch limbs within a 1-foot span the sum of whose diameters exceeds the d.o.b. at that point).

Board foot measure is computed from a squared-off section within the circular form of a log. This is the only portion that contains lumber. Therefore, ignore shallow defects expected to be cut in slabbing for lumber and rounding for veneer.

Determine the board foot cull volume in logs and/or cull sections by estimating the length and d.o.b. at midpoint and looking up the board foot volume in the "Board-foot Volume of Short Logs" table. In determining cull due to sweep and crook, minimize the defect by logical log-making aimed at obtaining maximum high grade material. Then use sweep and crook tables to determine the cull volume.

[3]*Doman, A. P.* et al. *1981.*

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Evaluating Oak Advance Reproduction In The Missouri Ozarks

Ivan L. Sander, Paul S. Johnson, and Robert Rogers

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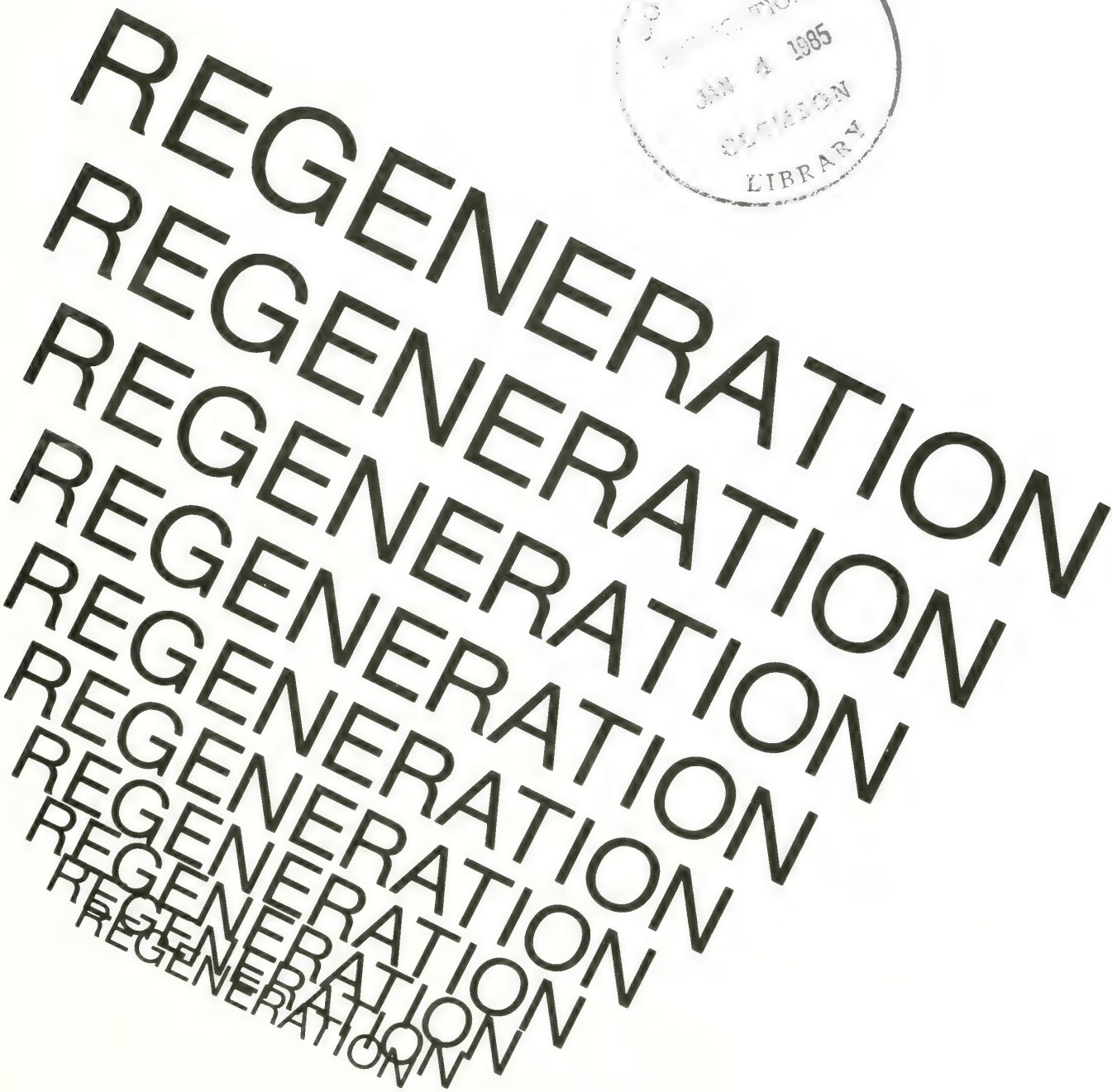

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EVALUATING OAK ADVANCE REPRODUCTION IN THE MISSOURI OZARKS

Ivan L. Sander, *Project Leader,*
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Columbia, Missouri

APPLICATION

This guide presents a method for determining in advance of final harvest whether reproduction is adequate to reasonably ensure the regeneration of an oak stand. The guide is based on studies of survival and growth of oak reproduction on a range of sites from site index 50 to 70 for black oak in the Missouri Ozarks. The guide assumes oaks will be grown in even-aged stands as recommended by Roach and Gingrich (1968) and Sander (1977).

The guide requires inventories of (a) the overstory and (b) the oak advance reproduction. Both inventories should be made at the same time and tallied on a form (fig. 1). If the oak advance reproduction inventory shows there are insufficient oaks to replace the stand, the overstory inventory is used to determine whether or not stump sprouts from overstory oaks are likely to be numerous enough to make up for deficiencies in advance reproduction.

To Use This Guide

1. Tally all oaks 1.6 inches d.b.h. and larger on 10 or more 1/20-acre plots by species and size classes (overstory inventory, see sample form (fig. 1)).

2. Determine average age of dominant and codominant oaks and site index from tables in Appendix II and record on the tally form. Also determine and record the average age of lower story (intermediate and suppressed) oaks that are 1.6 inches d.b.h. and larger.

3. Select the number of 1/735-acre plots (4.3 feet in radius) to use in the advance reproduction inventory from the following tabulation according to the acreage of the stand being examined:

For stand size (Acres)	Use this number of 1/735-acre plots
<10	25
10-30	40
30-50	60

4. Distribute these 1/735-acre plots uniformly throughout the stand.

5. Measure the tallest stem of advance oak reproduction on each 1/735-acre plot and record (advance reproduction inventory (fig. 1)). Tally these stems by 2-foot height classes and ½-inch ground diameter classes (table 1). A 6-inch caliper graduated in either tenth or quarter inches can be used for measuring ground diameters. Measure only trees 1.5 inches d.b.h. or less; stems larger than this should be considered part of the overstory and tallied as such, even if below the main canopy. If no oak advance reproduction is present, record zero for height and ground diameter on the tally form.

6. Record on the advance reproduction tally form the aspect of each plot by quadrant (NE, SE, SW, or NW) and its slope position (upper, middle, or lower thirds). For plots on level topography (all slopes less than 15 percent), narrow ridge tops, or bottoms, code as LE, RI, or BO, respectively, under slope position and use the stocking values for southeast/northwest aspects (table 1).

7. Determine the stocking value (SV) for each plot by referring to table 1 and record on the tally form. Then calculate the average SV and round off to the nearest whole number. If average SV is 30 percent or greater, oak advance reproduction is adequate; no further calculations are necessary and the stand can be harvested.

8. If the average SV is less than 30 percent, oak advance reproduction is inadequate to reproduce the stand if it is cut. But the stand can still be reproduced if enough stumps of the overstory oak trees will sprout after they are cut. To compute the contribution to reproduction stocking from expected stump sprouting:

a. Assume that the inventory of plots provides the data on the sample form (fig. 1).
b. Note that there are 26 black oaks 2 to 5 inches in diameter per acre. Multiply 26 by 0.42 (from table 2) to find how many of the 26 stumps are expected to produce codominant or dominant trees at age

Date 9/12/83 Compartment 1 Stand 10 Site Index 60

Stand Age(Dominants) 80 Stand Age(Lower story) 80

Overstory (1/20-acre plots)							Advance Reproduction (1/735-acre plots)					
Sample Point Number	D.B.H. Class	Black Oak	White Oak	Scarlet Oak	N. Red Oak	Other Spp.	Plot No.	Asp.	Slope Pos.	Ht.	Grnd. Dia.	SV
1	2-5	••	:·	·		••	1	SE	LO	0	0	0
	6-11		·			·	2	SE	LO	10	2.0	38
	12-16					·	3	SE	LO	0	0	0
	17+				·		4	SE	LO	2	.5	2
2	2-5	••	::				5	SE	LO	2	.5	2
	6-11	·	·			••	6	SE	LO	0	0	0
	12-16		·				7	SE	LO	6	1.5	23
	17+						8	SE	LO	4	.5	4
3	2-5	·	·	••		·	9	SE	LO	8	1.5	28
	6-11			·			10	SE	LO	0	0	0
	12-16		·			·	11	SE	LO	6	.5	8
	17+						12	SE	LO	0	0	0
4	2-5		••			:·	13	SE	LO	2	.5	2
	6-11						14	SE	MI	4	.5	18
	12-16	••		·		••	15	SE	MI	8	1.5	73
	17+						16	SE	MI	4	.5	18
5	2-5		::	••			17	SE	MI	8	1.5	73
	6-11	·	:·				18	SE	MI	0	0	0
	12-16						19	SE	MI	4	1.0	37
	17+		·				20	SE	MI	1	—	2
6	2-5	·	••	:·		••	21	SE	MI	8	1.0	64
	6-11					·	22	SE	MI	0	0	0
	12-16	••	·			·	23	SE	MI	6	1.5	65
	17+						24	SE	MI	4	1.5	56
7	2-5	:·	:·	••			25	SE	MI	8	1.5	73
	6-11		·			••	26	SE	MI	0	0	0
	12-16					·	27	SE	UP	10	2.0	79
	17+	·					28	SE	UP	0	0	0
8	2-5	••	·	·	••	:·	29	SE	UP	0	0	0
	6-11	·					30	SE	UP	8	1.5	68
	12-16	·			·		31	SE	UP	1	—	1
	17+						32	SE	UP	10	2.0	79
9	2-5		:·			••	33	SE	UP	0	0	0
	6-11	·			·	·	34	SE	UP	0	0	0
	12-16	••	·	·		·	35	SE	UP	6	1.5	59
	17+						36	SE	UP	0	0	0
10	2-5	••	::	·			37	SE	UP	0	0	0
	6-11		·		·	·	38	SE	UP	8	1.5	68
	12-16	••					39	SE	UP	6	1.5	59
	17+						40	SE	UP	1	—	1
Total No. Per Acre	2-5	26	60	24	4	26	140					
	6-11	8	12	2	4	22	48	SV Mean				25
	12-16	18	8	4	2	14	46					
	17+	2	2	0	2	0	6					
	Total	54	82	30	12	62	240	Advance Reproduction Adequate?				No
No. of Stump Spts. Per Acre	2-5	11	11	11	2							
	6-11	1	1	2	2		Total Per Acre	Advance Reproduction + Stump Sprouts Adequate?				Yes
	12-16	1	0	2	1							
	17+	0	0	0	0							
	Total	13	12	15	5		45					

Figure 1.—*Example tally form for recording overstory trees and oak advance reproduction stocking and for computing the number of expected oak stump sprouts.*

Table 1.—*Stocking value[1] for advance reproduction inventory plots*

Size of tallest tree per plot		Aspect and slope position of plot								
Height class (ft)	Ground diameter class	Southwest			Southeast & Northwest			Northeast		
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
	In.	*Plot Stocking Value (SV)*								
≤ 1	All	1	1	0	1	2	0	1	1	0
2	0.5 (0.3-0.7)	5	6	1	8	9	2	4	5	1
(1.1-3.0)	1.0 (.8+)	14	17	3	22	26	6	13	15	3
4	0.5 (.3-.7)	10	11	2	15	18	4	8	10	2
(3.1-5.0)	1.0 (.8-1.2)	22	25	6	32	37	9	19	22	5
	1.5 (1.3+)	37	42	11	51	56	18	34	38	10
6	0.5 (.3-.7)	19	22	5	28	32	8	16	19	4
(5.1-7.0)	1.0 (.8-1.2)	32	36	9	45	50	14	29	33	8
	1.5 (1.3+)	45	50	15	59	65	23	41	46	13
8	1.0 (.8-1.2)	44	49	14	59	64	22	40	45	12
(7.1-9.0)	1.5 (1.3-1.7)	54	59	19	68	73	28	49	54	17
	2.0 (1.8+)	62	67	24	76	80	35	57	62	21
10+	1.0 (.8-1.2)	58	63	22	72	77	32	54	59	14
(9.1+)	1.5 (1.3-1.7)	62	67	24	76	81	35	58	63	16
	2.0 (1.8-2.2)	66	71	27	79	84	38	61	66	19
	2.5 (2.3+)	69	74	29	82	86	41	64	69	21

Narrow ridge tops
Level areas (<15 percent slopes other than ridge tops and bottoms)
Bottoms

[1]Stocking Value (SV) is the contribution of a single stem to stand stocking at age 20.

20: 26 x 0.42 = 11 (rounded off to the nearest whole number). The expected number of stump sprouts per acre for 2- to 5-inch black oaks, 11, is listed at the bottom of figure 1.

c. Similarly, compute the expected number of stump sprouts for the other size classes of black oak (1 for the 6- to 11-inch class, 1 for the 12- to 16-inch class, and 0 for the 17+ inch class) and note that all these classes sum to 13. Do the same for all oak species.

d. Summing all oak species and all size classes gives a total of 45 expected stump sprouts per acre (fig. 1).

9. Go to table 3 and find the number of stump sprouts required in combination with advance reproduction stocking to meet minimum stocking requirements. Opposite 25 note that 37 stump sprouts are needed to make up the deficiency in advance reproduction. (Suppressed and intermediate oaks (particularly white oaks) may be younger than the stand dominants. Thus if 2- to 5-inch white oaks had been 40 years old instead of 80, expected stump sprouts from this diameter class would be 37 per acre—sufficient by themselves to compensate for the deficiency in advance reproduction. Consequently, the average age of lower story oaks should always be determined.)

10. Because the computed value (45) exceeds the tabulated value (37), oak stump sprouts will make up for deficiency in the advance reproduction. Thus, the oak component of the new stand will be adequate and the old stand can be harvested.

11. If the number of expected stump sprouts does not compensate for advance reproduction deficiencies, harvesting should be delayed until adequate oak advance reproduction is established. The alternative is to plant oak seedlings (Johnson [in prep.]).

12. To determine oak regeneration potential more rapidly, a program for Hewlett-Packard[1] programmable calculator is presented in Appendix III.

[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

Table 2.—*Expected proportion of stumps that will produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20*

Species	Site index	D.b.h. class	Age of parent tree (years) 40	60	80	100	All ages
		In					
Black oak[1]	50	2-5	0.36	0.34	0.32	0.30	—
		6-11	.13	.11	.10	.08	—
		12-16	.06	.05	.04	.03	—
		17+	—	.02	.02	.01	—
	60	2-5	.47	.45	.42	.40	—
		6-11	.16	.15	.13	.12	—
		12-16	.07	.06	.05	.04	—
		17+	—	.03	.02	.02	—
	70	2-5	.61	.59	.56	.54	—
		6-11	.21	.19	.17	.16	—
		12-16	.10	.08	.07	.06	—
		17+	—	.05	.04	.03	—
White oak[1]	50	2-5	.47	.25	.12	.05	—
		6-11	.18	.10	.06	.03	—
		12-16	.06	.04	.03	.02	—
		17+	—	.02	.01	.01	—
	60	2-5	.63	.38	.19	.08	—
		6-11	.26	.16	.09	.05	—
		12-16	.09	.07	.05	.03	—
		17+	—	.03	.02	.02	—
	70	2-5	.81	.55	.31	.15	—
		6-11	.36	.25	.16	.09	—
		12-16	.15	.11	.08	.06	—
		17+	—	.05	.04	.04	—
Northern red oak[2]	60+	2-5	.86	.86	.49	.49	—
		6-11	.86	.86	.46	.46	—
		12-16	.86	.86	.38	.38	—
		17+	—	.86	.24	.24	—
Scarlet oak[3]	50+	2-5	—	—	—	—	0.46
		6-11	—	—	—	—	.96
		12-16	—	—	—	—	.46
		17+	—	—	—	—	.10

[1]Values are based on data from Johnson (1977).
[2]Values are based on data from Wendel (1975) and Johnson (1975)
[3]Values by parent tree age are not available. Values given are means for sawtimber-size stands of various but unknown ages.

Table 3.—*Number of stump sprouts required to compensate for stocking deficiencies of advance reproduction*

Mean stocking value (SV) for 1/735-acre plots	Stump sprouts required
	Number per acre
≥30	0
29	8
28	15
27	23
26	30
25	37
24	45
23	52
22	59
21	67
20	74
19	81
18	89
17	96
16	103
15	111
14	118
13	125
12	133
11	140
10	148
9	155
8	162
7	170
6	177
5	184
4	192
3	199
2	206
1	214
0	221

DOCUMENTATION

Background

In even-aged stands, the oak component after final harvest cutting depends on size, number, and distribution of the oak advance reproduction (Sander 1971, 1972; Sander and Clark 1971). However, oak advance reproduction numbers differ greatly under mature stands. In the Missouri Ozarks, the number may range from less than 300 to more than 2,000 stems per acre.[2] Some of this variation is attributable to site quality—in general, oak advance reproduction is more abundant on average and poor sites than on good sites (Sander and Clark 1971).

Abundance of oak advance reproduction alone is not a good indicator of whether or not oaks will be a major component of a new stand after final harvest cutting. This is because much of the reproduction may be too small to successfully compete with associated vegetation. Thus, tree size, as well as tree numbers, should be considered in evaluating the oak regeneration potential.

Variation in oak advance reproduction size is related to recurrent stem dieback, which results in predominantly seedling-sprout populations in Ozark oak forests. Consequently, the root systems of large seedling-sprout reproduction are much older than the stems and are able to support much greater stem growth than recently established seedlings and small seedling-sprouts.

Both stem height and basal diameters of oak advance reproduction are related to growth after overstory removal (McQuilkin 1975, Sander 1971). Thus both height and diameter are indicators of total plant size and the potential of the root systems to support vigorous shoot growth after overstory removal.

Estimating fifth-year "success" probabilities.—To determine the relation between oak advance reproduction size and development after overstory removal, we measured 394 stems in 6 stands in the Missouri Ozarks before and after clearcutting. Eighty-five percent of these stems were black oak (*Quercus velutina* Lam.) and white oak (*Q. alba* L.) and the remainder were scarlet oak (*Q. coccinea* Muenchh.) and northern red oak (*Q. rubra* L.). These trees were well distributed across all aspects and slope positions in stands with black oak site index 50 to 70 (McQuilkin 1974).

We chose oak stump sprouts as the standard for determining oak reproduction success because of their rapid growth and predominance in the upper crown strata of these 5-year-old stands. We defined a "successful" oak as one that had attained at least 80 percent of the mean height of all oak stump sprouts measured. These stump sprouts averaged 11 feet tall at age 5 so to be "successful" an oak had to be at least 8.8 feet tall. Eighty percent was chosen as the success criterion because nearly all oaks at least 8.8 feet tall at age 5 were dominant or codominant. Using this criterion for success and initial and 5 year measurements, we developed equations for predicting the probability of success for an individual stem of a given size using logistic regression analysis (Engelman 1981). In addition to initial tree height and basal

diameter, we used aspect and slope position to predict success probability (Appendix I). These success probabilities did not differ significantly by species ($P < 0.05$) so the resulting estimates are for all four species combined.

The regression estimates showed that success probabilities increase with increasing initial height and ground diameter. In addition, probabilities were highest on southeast and northwest aspects and on middle slope positions. Initial size being equal, probabilities of success were lowest on northeast facing slopes and on lower slope positions. Probabilities of success ranged from less than 0.01 for 1-foot tall trees of small diameter on lower slopes to 0.88 for trees 10 feet tall with large (2.5-inch) ground diameters on middle slopes of southeast or northwest aspects. In general these relations reflect a low likelihood of tree development in environments where soil moisture is extremely favorable or unfavorable. This relation may in turn be related to high mortality and/or poor growth on droughty sites and severe competition on moist sites.

Establishing A Future Stocking Goal

Determining the minimum amount of oak advance reproduction for adequate stocking in a new stand requires first defining "adequate stocking." At some future stage of stand development enough dominant and codominant oaks must be in the stand to furnish some minimum stocking level. The stage chosen for this guide is when the mean stand diameter is 3 inches. The goal we've selected is to have the stand at least 30 percent stocked (C level) with codominant and dominant oaks at this mean stand diameter. Total stand stocking will be higher because trees of other species and probably some smaller oaks will be present.

Unmanaged oak stands on average sites (black oak site index 60-75) in a Missouri study reached a mean stand diameter of 3 inches at age 20 to 25, and the dominant and codominant trees averaged 4.5 inches in diameter[2]. According to Gingrich's (1967) equation for defining minimum tree area requirements, one 4.5-inch tree contributes 0.136 percent stocking and requires 1.36 milacres of growing space. To attain the 30 percent stocking goal requires 30/0.136 or 221 trees averaging 4.5 inches in diameter when the mean stand diameter is 3 inches.

Estimating the Contribution of Advance Reproduction to Future Stand Stocking

Advance reproduction's contribution to future stand stocking depends on its future utilization of growing space. This is generally not practical to measure until the stand reaches a mean stand diameter of 3 inches—the lowest mean diameter shown on Gingrich's (1967) stocking chart. Because this occurs at about age 20, we extended fifth-year success probabilities (P5) to age 20 to estimate the advance reproduction contribution. We assumed a 1 percent per year loss of trees deemed successful the fifth year to mortality and suppression over the next 15 years (Sander *et al.* 1976). The resulting probabilities (P20) are thus estimates of the proportion of advance reproduction stems expected to be codominant or dominant at age 20.

Given these probabilities (P20), we then determined the number of oak advance reproduction stems (R) required to produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20 by using the following relation based on the binomial probability distribution:

$$R = \log(1-0.8)/\log(1-P20) \quad (1)$$

(Johnson 1976, Leak 1969). We selected 0.8 as a "confidence" probability because, it is a compromise between excessively high stocking requirements resulting from the use of a higher confidence probability on the one hand and an unacceptably low confidence in P20 on the other hand. The probability that *one* advance reproduction stem of a given size becomes codominant or larger 20 years after final harvest at least 80 percent of the time is then 1/R. Expressed as a percent, 1/R is referred to as a stocking value (SV) because it defines the contribution of a stem to future stand stocking and can be used to quantify the stocking of an individual plot.

The average stocking value for a stand based on an inventory using 1/735-acre plots is the percent of the 735 growing spaces expected to produce codominant or dominant oaks at a mean stand diameter of 3 inches (about age 20). This percent must then equal or exceed 30 (i.e., (221/735)100) for oak advance reproduction to be adequate and fulfill minimum future stocking requirements based on the 221 tree goal.

Sample Plot Size and Number

The appropriate unit for sampling oak advance reproduction should be related to the average size (4.5 inches d.b.h.) of dominant and codominant trees when the mean stand diameter is 3 inches. A 4.5-inch tree requires 1.36 milacres or 1/735-acre of growing space. Theoretically, then, on any given acre the opportunity exists for each 1/735-acre to contain one 4.5-inch tree. At or beyond a mean stand diameter of 3 inches, more than one codominant or larger tree would not be expected to persist within this sample space. Thus the appropriate plot size is 1/735-acre (4.3-feet radius).

The number of 1/735-acre plots shown on page one is a reasonable estimate of the minimum number of sample plots needed for inventorying advance reproduction. If greater precision is desired, a preliminary sample should be used to estimate confidence limits and the required number of plots for a given level of precision should be calculated based on the binomial distribution (Freese 1962).

THE ROLE OF STUMP SPROUTS

The potential for sprouting from stumps of overstory oaks can be used to compensate for deficiencies in oak advance reproduction when evaluating the oak reproduction potential of a stand. Stump sprouts are the fastest growing oak component in new stands and those of low origin generally develop into good quality trees.

Factors shown to influence oak stump sprouting in a Missouri study include parent tree age and d.b.h. and site quality. Sprouting frequency decreases with both increasing parent tree age and d.b.h. but increases with increasing site quality. These relations were used to develop equations to estimate the proportion of parent trees that would produce codominant or larger black, white, and scarlet oaks at age 5 (Johnson 1977). These proportions were adjusted for anticipated mortality to stand age 20 by assuming a population reduction of 0.75 percent per year for 15 years. This adjustment was based on a 32-year stump sprout study (Roth and Hepting 1969). Data from Wendel (1975) and Johnson (1975) were similarly used to estimate proportions for northern red oak.

Using these adjusted proportions, values of R were calculated by using equation (1); 1/R was then used as the estimate of the proportion of parent trees expected to produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20 (table 2). For black oak and white oak, expected proportions are shown by parent tree age, parent tree d.b.h., and site index. Age and site index information were not available for scarlet oak, so proportions are given by diameter classes only. The latter values are averages for sawtimber-size stands in the Missouri Ozarks. Proportions for northern red oak are based on data from parent stands in West Virginia that were 50- to 55-years-old on site index 60 to 80, and from stands in Wisconsin that ranged from about 70- to 110-years-old on site index 50 to 70 (Wendel 1975, Johnson 1975). Season of cutting may also influence stump sprouting and subsequent sprout development (Wendel 1975, Clark and Liming 1953), so we took this into account when determing these probabilities.

The minimum number of stump sprouts per acre (N) required to compensate for deficiencies in advance reproduction is:

$$N = 221 - \overline{SV}(7.35),$$

where $\overline{SV}$ is the mean stocking value for oak advance reproduction obtained by applying stocking values for advance reproduction inventory plots (table 1) to an inventory of 1/735-acre plots (table 3). This minimum number of trees can then be compared to the estimated number of expected stump sprouts to determine if advance reproduction plus stump sprouts will be adequate to replace the old stand.

IN CONCLUSION

The guide presents a method for obtaining "best available" estimates of the regeneration potential for Ozark oak forests based on currently available information. How well the guide works can be determined only by how many oaks grow fast enough to maintain themselves in a good competitive position as the stand develops. We used data from six Missouri Ozark stands to make a small test of the guide's ability to predict "success." Based on the number of oaks per acre at least 8 feet tall at age 5 the guide predicted "success" correctly in 5 of the 6 stands.

We hope silviculturists will apply the guide conscientiously and test its validity by inventorying reproduction at periodic intervals after harvest cutting. We hope users will share their results with us. In this way we can be made aware of the guide's shortcomings or strengths and what revisions may be needed. It will be revised as experience in application and new information dictates.

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APPENDIX I.

Regression coefficients for the equation for estimating fifth-year success probabilities (P5) for oak advance reproduction[1]

Independent variable	Regression coefficient (B)[2]
X1: Square root of tree ground diameter (in)	5.10
X2: Total tree height (ft)	0.700
X3: X1 x X2	-0.444
X4: Log(success criterion)[3]	-5.95
X5: Aspect(V1)[4]	-0.284
X6: Aspect(V2)[4]	0.404
X7: Slope position(V1)[5]	-1.10
X8: Slope position(V2)[5]	0.646
Constant (B_0)	19.0

[1]The equation is of the form:

$$P5 = 1 + \exp[-B_0 + B_1X_1 + \ldots B_nX_n)]^{-1},$$

where P5 is the probability that an individual stem of oak advance reproduction will attain or exceed the success criterion set by the value of X4.

[2]All regression coefficients are significant at the 0.01 level. Goodness of fit was also evaluated by chi-square (Engelman 1981). Total number of observations in the regression data set was 2,364.

[3]X4 = the natural logarithm of the selected success criterion (a percent). We solved the equation for a success criterion of 80, i.e., 80 percent of mean stump sprout height at age 5. At that age stump sprouts averaged 11 feet tall, and those that were 80 percent or more of that height (i.e., at least 8.8 feet tall) were usually codominant or dominant and thus "successful". However, the equation can be solved for any success criterion (e.g., 70 or 90 percent).

[4]X5 and X6 are vectors (V) of the independent variable "aspect" that *jointly* express the aspect effect on the estimate of P5. Coded values of X for both vectors are given below for the four aspects considered.

Aspect	Value of X for vector Aspect(V1)	Aspect(V2)
SW	-1	-1
SE and NW	0	1
NE	1	0

[5]X7 and X8 are vectors (V) of the independent variable "slope position" that *jointly* express the slope position effect on the estimate P5. Coded values of X for both vectors are given below for the three slope positions considered.

Slope position	Value for X for vector Slope position(V1)	Slope position(V2)
Upper third	-1	-1
Middle third	0	1
Lower third	1	0

To simplify application, we used categorical values of aspect and slope position instead of continuous values such as degrees azimuth and percent of distance from the ridge. The values of these categorical variables are based on "effects" coding and are generated by the logistic regression program (Engleman 1981); the statistical properties of the resulting coefficients are discussed by Kerlinger and Pedhazur (1973, pp. 121-128).

APPENDIX II.— Determining Site Index

1. Select at least 5, preferably 10, straight undamaged dominant or codominant trees per stand that show no signs of suppression. Selected trees should not differ more than 5 years in age from the trees immediately surrounding them.
2. Measure tree height and breast-height age; add 2 years to breast-height age to get total age.
3. Calculate average height and age and look up site index in tables 4 and 5.
4. Approximate conversions between species may be made as follows:
   Black oak SI = Scarlet oak SI-3
   Black oak SI = White oak SI+4
   Scarlet oak SI = Black oak SI+3
   White oak SI = Black oak SI-4.

Table 4.--*Black and scarlet oak site index estimates by 2-foot height and 2-year age intervals*[1]/ *(McQuilkin 1974)*

Age (years)	Height (feet) 8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
10		55	57	59	61	63	64	66	68	70	72																																
12			54	56	58	60	62	63	65	67	69	71																																
14				53	55	57	59	61	62	64	66	68	70	72	74																														
16					52	54	56	58	60	62	63	65	67	69	71	73	75																												
18						51	53	55	57	59	60	62	64	66	68	70	72	74	76	78																								
20							50	52	54	56	58	60	61	63	65	67	69	71	73	75	77	79																						
22								49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																						
24									48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																					
26										48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																				
28										45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	76																				
30											45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																			
32												45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																		
34													45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																	
36													42	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	78															
38														42	44	47	49	51	53	55	57	59	61	63	65	67	69	71	74	76	78													
40															42	44	47	49	51	53	55	57	59	61	63	65	67	70	72	74	76	78												
42																43	45	47	49	51	54	56	58	60	62	64	66	68	70	72	74	76	78	80										
44																	44	46	48	50	52	54	56	58	60	62	64	67	69	71	73	75	77	79	81									
46																	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81								
48																		43	45	47	49	51	53	55	57	59	61	64	66	68	70	72	74	76	78	80	82							
50																			44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82						
52																				45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81						
54																				44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	75	77	79	81					
56																				43	45	47	49	51	53	55	57	59	61	63	65	67	68	70	72	74	76	78	80					
58																					44	46	48	50	52	54	56	58	60	62	63	65	67	69	71	73	75	77	79	81				
60																					44	45	47	49	51	53	55	57	59	60	62	64	66	68	70	72	74	75	77	79				
62																					43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71	73	74	76	78	80			
64																					42	44	46	48	50	51	53	55	57	59	61	62	64	66	68	70	71	73	75	77	79			
66																						43	45	47	49	51	52	54	56	58	60	61	63	65	67	69	70	72	74	76	78	79		
68																						43	45	46	48	50	52	53	55	57	59	61	62	64	66	68	69	71	73	75	76	78		
70																						42	44	46	47	49	51	53	54	56	58	60	61	63	65	67	68	70	72	74	75	77	78	
72																						42	44	46	47	49	51	52	54	56	57	59	61	62	64	66	68	69	71	73	74	76	78	
74																							44	45	47	49	50	52	54	55	57	59	60	62	64	65	67	68	70	72	73	75	77	
76																							43	45	47	48	50	52	53	55	56	58	60	61	63	64	66	68	69	71	73	74	76	
78																								45	46	48	50	51	53	54	56	58	59	61	62	64	65	67	69	70	72	73	75	
80																									45	46	48	49	51	52	54	55	57	59	60	62	63	65	66	68	69	71	72	74

[1]/ All height and age combinations in this table are within the range of the original black oak data; height and age combinations within the lines indicate the range of the original scarlet oak data.

Table 5.--*White oak site index estimates by 2-foot height and 2-year age intervals*[1/] *(McQuilkin 1974)*

| Age (years) | Height (feet) | | |

APPENDIX III

OAKREGEN: HP41C, a program for computing average stocking value and expected stump sprouting. This 1862 byte program can be run only on a Hewlett-Packard HP41CV or an HP41C with four memory modules added. A printer is desirable but not neccessary. Clear the calculator of all programs, reserve 51 registers for data by pressing the following keys [XEQ] [ALPHA] SIZE [ALPHA] 051, and then key in the OAKREGEN program listed below.

HOW TO USE THE PROGRAM

A. To determine if advance reproduction alone is adequate press [XEQ] [ALPHA] AR [ALPHA] and you will be prompted to enter advance reproduction data. Press [R/S] after you enter each number. Use the following codes for aspect and slope position:

ASPECT	CODE	SLOPE POSITION	CODE
SW	1	Upper	1
SE & NW	2	Middle	2
NE	3	Lower	3

If there are no trees on a plot, press [R/S] when prompted for aspect.

After all data has been entered, calculate average stocking value by pressing [XEQ] [ALPHA] SV [ALPHA] .

B. To determine the contribution of stump sprouts to future stocking press [XEQ] [ALPHA] OV [ALPHA] and enter overstory data when prompted. Press [R/S] after entering each number. After all data has been entered, calculate the number of stump sprouts expected per acre by pressing [XEQ] [ALPHA] ST [ALPHA] .

```
01♦LBL "OV"
02♦LBL 01
03 FIX 3
04 0
05 0.01601
06 STO 50
07♦LBL 03
08 0
09 STO IND 50
10 ISG 50
11 GTO 03
12 STO 48
13 "PLOT SIZE? "
14 PROMPT
15 STO 17
16 ARCL 17
17 AVIEW
18 FIX 0
19 "STAND AGE? "
20 PROMPT
21 STO 18
22 ARCL 18
23 AVIEW
24 "SITE INDEX? "
25 PROMPT
26 STO 19
27 ARCL 19
28 AVIEW
29 ADV
30♦LBL 02
31 ADV
32 1.01601
33 STO 50
34 1
35 ST+ 00
36 RCL 00
37 "POINT="
38 ARCL 00
39 AVIEW
40 0
41 "BO 2-5? "
42 XEQ 90
43 "BO 6-11? "
44 XEQ 90
45 "BO 12-16? "
46 XEQ 90
47 "BO 17+? "
48 XEQ 90
49 "WO 2-5? "
50 XEQ 90
51 "WO 6-11? "
52 XEQ 90
53 "WO 12-16? "
54 XEQ 90
55 "WO 17+? "
56 XEQ 90
57 "SO 2-5? "
58 XEQ 90
59 "SO 6-11? "
60 XEQ 90
61 "SO 12-16?"
62 XEQ 90
63 "SO 17+? "
64 XEQ 90
65 "RO 2-5? "
66 XEQ 90
67 "RO 6-12? "
68 XEQ 90
69 "RO 12-16? "
70 XEQ 90
71 "RO 17+? "
72 XEQ 90
73♦LBL 90
74 PROMPT
75 ARCL X
76 AVIEW
77 ST+ IND 50
78 0
79 ISG 50
80 RTN
81 GTO 02
82♦LBL "ST"
83 RCL 00
84 1
85 -
86 STO 00
87 "***************"
88 AVIEW
89 ADV
90 "STUMPS PER ACRE"
91 AVIEW
92 "BO.WO.SO.RO."
93 AVIEW
94 CLA
95 1.01304
96 "2-5: "
97 XEQ 05
98 2.01404
99 "6-11: "
100 XEQ 05
101 3.01504
102 "12-16: "
103 XEQ 05
104 4.01604
105 "17+: "
106 XEQ 05
107 1.01701
108 STO 50
109 6.00901
110 STO 49
111♦LBL 10
112 3.5
113 XEQ IND 49
114 ISG 50
115 CLD
116 8.5
117 XEQ IND 49
118 ISG 50
119 14
120 XEQ IND 49
121 ISG 50
122 19.5
123 XEQ IND 49
124 ISG 50
125 ISG 49
126 GTO 10
127 CLA
128 ADV
129 "SPROUTS PER AC."
130 AVIEW
131 "BO.WO.SO.RO."
132 AVIEW
133 1.01304
134 "2-5: "
135 XEQ 56
136 2.01404
137 "6-11: "
138 XEQ 56
139 3.01504
140 "12-16: "
141 XEQ 56
142 4.01604
143 "17+: "
144 XEQ 56
145 ADV
146 "TOTAL SPROUTS= "
147 "+ "
148 ARCL 48
149 AVIEW
150 STOP
151♦LBL "AR"
152 0
153 STO 31
154 ADV
155 "ADV REP"
156 AVIEW
157 0
158 STO 22
159♦LBL 11
160 1
161 ST+ 22
162♦LBL 39
163 "PLOT= "
164 ARCL 22
165 AVIEW
166 23.02601
167 STO 50
168 "ASPECT? "
169 SF 01
170 0
171 XEQ 95
172 "SLOPE? "
173 0
174 XEQ 95
175 "HEIGHT? "
176 .5
177 FIX 1
178 SF 00
179 XEQ 95
180 0
181 "DIA? "
182 .2
183 SF 02
184 XEQ 95
185 FIX 0
186 RCL 23
187 1
188 X=Y?
189 GTO 12
190 RCL 23
191 2
192 X=Y?
193 GTO 13
194 RCL 23
195 3
196 X=Y?
197 GTO 14
198♦LBL 38
199 "BAD ENTRY"
200 AVIEW
201 GTO 39
202♦LBL 18
203 RCL 24
204 1
205 X=Y?
206 GTO 15
207 RCL 24
208 2
```

```
209 X=Y?
210 GTO 16
211 RCL 24
212 3
213 X=Y?
214 GTO 17
215 GTO 38
216♦LBL 19
217 RCL 26
218 SQRT
219 5.1
220 *
221 RCL 25
222 .7
223 *
224 +
225 RCL 26
226 SQRT
227 RCL 25
228 *
229 -.444
230 *
231 +
232 -26.0731
233 +
234 RCL 27
235 -.284
236 *
237 +
238 RCL 28
239 .404
240 *
241 +
242 RCL 29
243 -1.1
244 *
245 +
246 RCL 30
247 .646
248 *
249 +
250 19
251 +
252 CHS
253 E↑X
254 1
255 +
256 1/X
257 .85
258 *
259 1
260 X<>Y
261 -
262 LN
263 .2
264 LN
265 X<>Y
266 /
267 1/X
268 100
269 *
270♦LBL 40
271 RND
272 "STOCKING VALUE="
273 "⊢ "
274 ARCL X
275 AVIEW
276 ST+ 31
277 ADV
278 GTO 11
279♦LBL 12
280 -1
281 STO 27
282 STO 28
283 GTO 18
284♦LBL 13
285 0
286 STO 27
287 1
288 STO 28
289 GTO 18
290♦LBL 14
291 1
292 STO 27
293 0
294 STO 28
295 GTO 18
296♦LBL 15
297 -1
298 STO 29
299 STO 30
300 GTO 19
301♦LBL 16
302 0
303 STO 29
304 1
305 STO 30
306 GTO 19
307♦LBL 17
308 1
309 STO 29
310 0
311 STO 30
312 GTO 19
313♦LBL "SV"
314 ADV
315 "STOCKING VALUE "
316 "⊢MEAN= "
317 RCL 31
318 RCL 22
319 1
320 -
321 /
322 RND
323 STO 32
324 ARCL X
325 AVIEW
326 29
327 X<>Y
328 X>Y?
329 GTO 80
330 RCL 32
331 ADV
332 7.35
333 *
334 CHS
335 221
336 +
337 "ADV REPRO"
338 AVIEW
339 "NOT ADEQ."
340 AVIEW
341 "MIN SPROUTS NEE"
342 "⊢DED= "
343 ARCL X
344 AVIEW
345 STOP
346♦LBL 80
347 "ADV REPRO"
348 AVIEW
349 "ADEQUATE"
350 AVIEW
351 STOP
352♦LBL 95
353 PROMPT
354 FS? 00
355 GTO 96
356 FS? 01
357 GTO 60
358♦LBL 70
359 X<=Y?
360 X<>Y
361 FS? 00
362 XEQ 68
363 FS? 02
364 XEQ 65
365 ARCL X
366 AVIEW
367 STO IND 50
368 ISG 50
369 RTN
370 RTN
371♦LBL 60
372 CF 01
373 X=0?
374 GTO 40
375 GTO 70
376♦LBL 96
377 CF 00
378 X=0?
379 GTO 97
380 SF 00
381 GTO 70
382♦LBL 97
383 0
384 ST+ 31
385 ARCL X
386 AVIEW
387 FIX 0
388 GTO 40
389♦LBL 65
390 2.5
391 X<>Y
392 X>Y?
393 X<>Y
394 CF 02
395 RTN
396♦LBL 68
397 10
398 X<>Y
399 X>Y?
400 X<>Y
401 CF 00
402 RTN
403♦LBL 04
404 RCL IND 50
405 RCL 00
406 RCL 17
407 *
408 1/X
409 *
410 ARCL X
411 ISG 50
412 GTO 04
413 AVIEW
414 RTN
415♦LBL 05
416 STO 50
```

```
417 XEQ 04
418 CLA
419 RTN
420*LBL 07
421 STO 20
422 1.1462
423 *
424 .4323
425 +
426 STO 21
427 RCL 21
428 RCL 18
429 *
430 .00211455
431 *
432 RCL 19
433 X↑2
434 .000511196
435 *
436 +
437 RCL 18
438 -.0564873
439 *
440 +
441 RCL 21
442 -.252517
443 *
444 +
445 2.23305
446 +
447 CHS
448 E↑X
449 1
450 +
451 1/X
452 RCL 21
453 1/X
454 18.3965
455 *
456 -.847819
457 +
458 CHS
459 E↑X
460 1
461 +
462 1/X
463 *
464 .8875
465 *
466 1
467 X<>Y
468 -
469 LN
470 .2
471 LN
472 X<>Y
473 /
474 1/X
475 RCL IND 50
476 *
477 RND
478 ST+ 48
479 STO IND 50
480 RTN
481*LBL 06
482 STO 20
483 1.1462
484 *
485 .4323
486 +
487 STO 21
488 RCL 18
489 *
490 -.00101597
491 *
492 RCL 19
493 X↑2
494 .000415282
495 *
496 +
497 -.785279
498 +
499 CHS
500 E↑X
501 1
502 +
503 1/X
504 RCL 21
505 1/X
506 24.3594
507 *
508 -2.5782
509 +
510 CHS
511 E↑X
512 1
513 +
514 1/X
515 *
516 .8875
517 *
518 1
519 X<>Y
520 -
521 LN
522 .2
523 LN
524 X<>Y
525 /
526 1/X
527 RCL IND 50
528 *
529 RND
530 ST+ 48
531 STO IND 50
532 RTN
533*LBL 08
534 STO 20
535 3.5
536 X<>Y
537 X>Y?
538 GTO 88
539 .46
540 RCL IND 50
541 *
542 RND
543 ST+ 48
544 STO IND 50
545 RTN
546*LBL 88
547 RCL 20
548 1.1462
549 *
550 .4323
551 +
552 STO 21
553 .23840565
554 *
555 RCL 21
556 X↑2
557 .00278134
558 *
559 CHS
560 +
561 RCL 21
562 1/X
563 8.2488119
564 *
565 CHS
566 +
567 RCL 21
568 LOG
569 5.68040348
570 *
571 CHS
572 +
573 4.45376108
574 +
575 10↑X
576 RCL 21
577 X<>Y
578 -
579 STO 21
580 .59484
581 *
582 CHS
583 RCL 21
584 X↑2
585 100
586 /
587 +
588 1.02390
589 +
590 6.90428
591 +
592 CHS
593 E↑X
594 1
595 +
596 1/X
597 RCL 21
598 3
599 Y↑X
600 .00344484
601 *
602 RCL 21
603 X↑2
604 .161127
605 *
606 CHS
607 +
608 RCL 21
609 2.11955
610 *
611 +
612 6.11437
613 CHS
614 +
615 CHS
616 E↑X
617 1
618 +
619 1/X
620 *
621 .8875
622 *
623 1
624 X<>Y
```

```
625 -
626 LN
627 .2
628 LN
629 X<>Y
630 /
631 1/X
632 RCL IND 50
633 *
634 RND
635 ST+ 48
636 STO IND 50
637 RTN
638*LBL 09
639 STO 20
640 RCL 18
641 60
642 X<>Y
643 X>Y?
644 GTO 99
645 .86
646 RCL IND 50
647 *
648 RND
649 ST+ 48
650 STO IND 50
651 RTN
652*LBL 99
653 RCL 20
654 3.5
655 X<>Y
656 X>Y?
657 GTO 98
658 4
659 STO 20
660*LBL 98
661 RCL 20
662 3
663 Y↑X
664 .0032
665 *
666 CHS
667 57.3
668 +
669 .00955
670 *
671 1
672 X<>Y
673 -
674 LN
675 .2
676 LN
677 X<>Y
678 /
679 1/X
680 RCL IND 50
681 *
682 RND
683 ST+ 48
684 STO IND 50
685 RTN
686*LBL 55
687 .5
688 RCL IND 50
689 X<=Y?
690 0
691 ARCL X
692 ISG 50
693 GTO 55
694 AVIEW
695 RTN
696*LBL 56
697 STO 50
698 XEQ 55
699 CLA
700 RTN
701 .END.
```

LABELS

CAT 1

```
LBL'OV
LBL'ST
LBL'AR
LBL'SV
.END.       1862 BYTES
```

U.S. GOVERNMENT PRINTING OFFICE: 1984—767-046/10047

Sander, Ivan L.; Johnson, Paul S.; Rogers, Robert.
Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 16 p.

This guide presents a method for determining in advance of final harvest whether reproduction is adequate to reasonably ensure the regeneration of an oak stand in the Missouri Ozarks.

KEY WORDS: Quercus, stump sprouts, inventory, and final harvest.

40th BIRTHDAY
SMOKEY
1944
1984
PREVENT FOREST FIRES

United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-252**

STEMS: A Nontechnical Description for Foresters

Cynthia L. Miner and Nancy R. Walters

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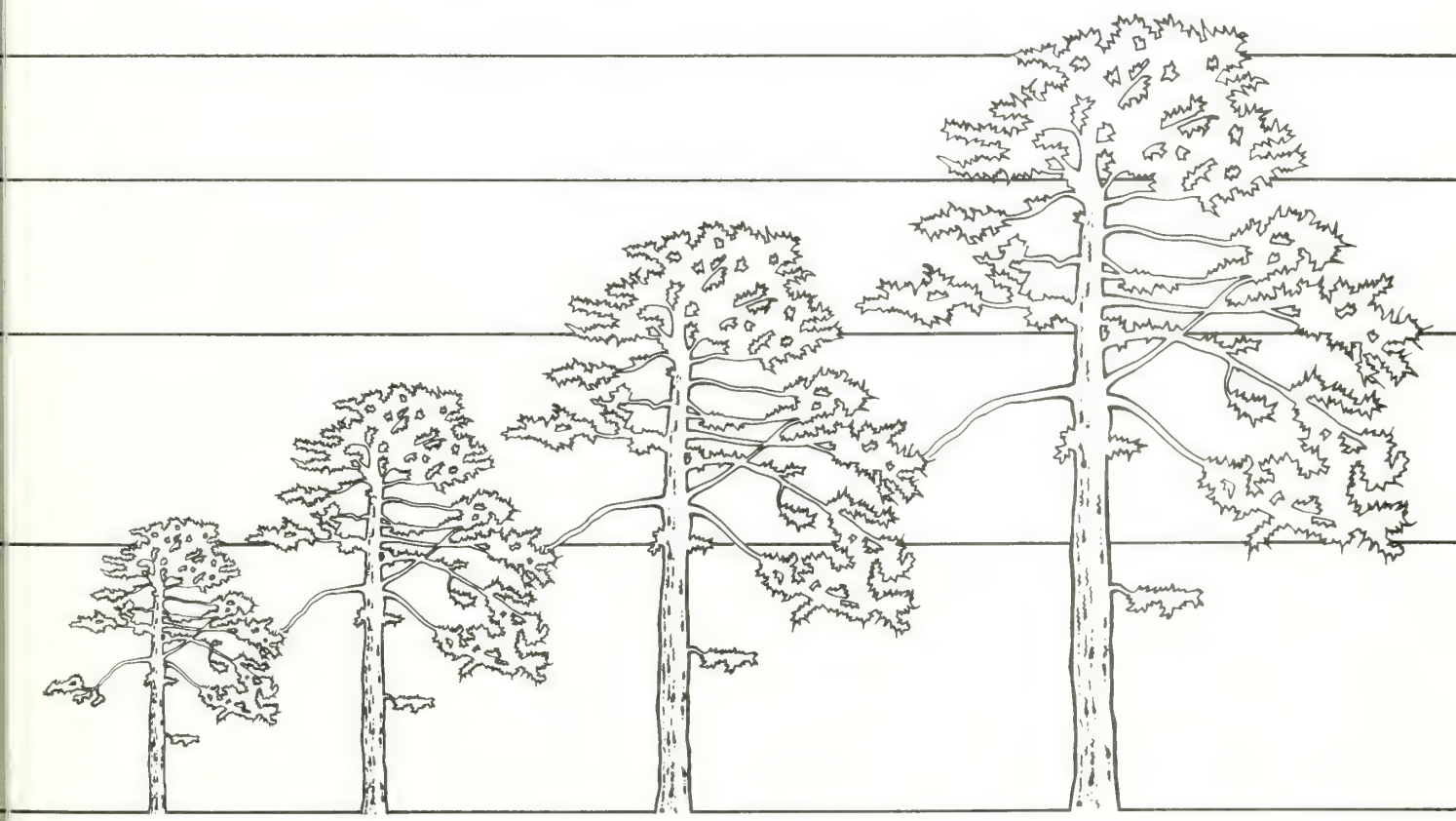

CONTENTS

	Page
Input	1
Tree Lists	1
User Options	2
Interactive and Batch Versions	2
Growth Projections	3
Potential Tree Growth	3
Growth Modifier	4
Tree Mortality	4
Timber Management	4
Prescription Standards	5
Marking	6
Regeneration	7
Output	8
Applications	10
Summary	10
Literature Cited	10
Appendix	10
Mortality	10
Probabilistic vs. Deterministic Mortality	11
Afterword	11

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STEMS: A NONTECHNICAL DESCRIPTION FOR FORESTERS

Cynthia L. Miner, *Forester,*
and **Nancy R. Walters,** *Forester*

Forest managers have long wished for a view of tomorrow's forests that reflects today's decisions. For the past 20 years researchers have been developing computer models of future stands by using past forest changes and mathematics as building blocks. In 1975, research was begun at the North Central Forest Experiment Station to model forest changes. The result of this research is the Stand and Tree Evaluation and Modeling System (STEMS).

The future of a forest depends on the birth, growth, and death of trees. STEMS simulates the life cycle and management of trees native to the Lake States (Michigan, Minnesota, and Wisconsin), and Central States (Indiana, Illinois, and Missouri). Individual trees, any of 95 species in the Central States and 47 species in the Lake States, are "grown" and "managed" in stands of any age or species combination.

STEMS consists of two linked programs (fig. 1): the Tree Growth Projection System (TGPS), the essential part of STEMS that simulates tree growth, mortality, timber management, and regeneration; and Table (TABL), an optional program that produces detailed summaries from TGPS.

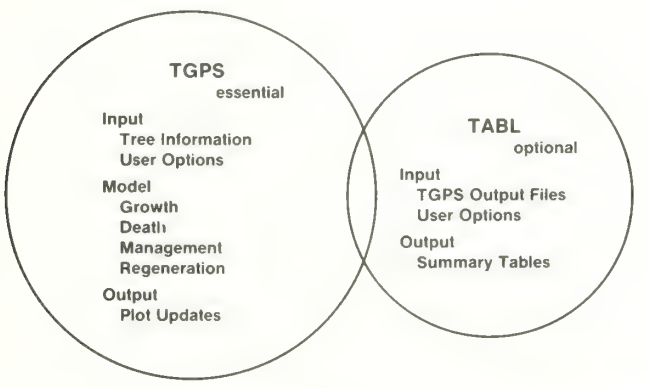

Figure 1.—*TGPS and TABL, the two linked programs of STEMS.*

TGPS contains most of the building blocks for modeling a forest; however, it is the STEMS user who determines the model's final outcome by providing initial tree information and choosing options available in STEMS. Although knowing how to program computers enhances STEM's flexibility, even novice computer users can tailor stand growth, management, and output to fit their needs.

Because STEMS does not integrate forest management factors such as tree spacing, slope, understory vegetation, catastrophes, and forest use, it cannot be used to produce "cookbook" prescriptions. But STEMS can update past inventories, project future yields, and help evaluate alternatives for timber management. When combined with a forester's skills and subjective judgments, STEMS becomes a valuable management tool.

INPUT

To simulate growth and management, STEMS needs two types of information from the user: (1) a tree list representing a valid sample of a homogeneous area to be examined and (2) selections from STEMS computer options.

Tree Lists

Lists can be created for hypothetical forest stands or drawn from field inventory data cards taken from variable or fixed-radius plots. To obtain accurate growth projections, the list must be a valid representation of the plot, whether the plot represents part of a stand, all of a stand, or a group of stands.

A tree list must be in a format that STEMS can read. You either type the list in this format onto a computer file or call another computer program, TREEGEN, to arrange your list in the required format (fig. 2).

PROP/PLOT=HAWK12C AGE= 55 SITE= 45 YEAR=1985

TREE NUMB	SPECIES	DBH	CROWN RATIO	EXPANS FACTOR	STATUS	"STEMS" SPGP	TREE CLASS
1	241.	11.2	6.0	6.5	1	8	20
2	543.	3.6	3.0	9.9	1	11	20
3	543.	7.0	3.0	6.8	1	11	20
4	543.	4.6	2.0	9.9	1	11	20
5	241.	8.7	6.0	2.2	1	8	20
6	94.	10.5	6.0	7.6	1	4	20
7	543.	8.0	3.0	2.2	1	11	20
8	543.	7.3	3.0	9.1	1	11	40
9	543.	9.9	3.0	7.6	1	11	20
10	543.	10.2	2.0	7.0	1	11	20
11	241.	9.4	7.0	8.9	1	8	20
12	543.	10.8	3.0	6.6	1	11	20
13	241.	10.2	6.0	8.1	1	8	20
14	972.	9.2	3.0	10.0	1	15	20
15	972.	11.0	3.0	7.0	1	15	20
16	12.	8.6	7.0	3.3	1	5	20
17	741.	12.1	2.0	5.4	1	25	20

Figure 2.—*Tree list for plot 12C in format used by STEMS.*

Plot data needed by STEMS include: present age, year when measured, and site index, as well as property and plot identification.

Information needed for each tree includes:

1. species code
2. d.b.h.—diameter at breast height
3. crown ratio—fraction of total tree height in live crown (optional)
4. tree expansion factor—number of trees per acre that each tree in the list represents[1]
5. tree status—live or dead
6. STEMS SPGP—species group assigned by STEMS, i.e. northern hardwood
7. tree class—acceptable, rough, short sawtimber, rotten, or wildlife.

If detailed tree information is not available, TREEGEN can generate the tree list from plot averages. For this, you specify plot species groups, number of trees per acre, and information about the distribution of trees by diameter class.

User Options

After the tree list is generated and entered into STEMS, you choose from several options that determine the characteristics of growth projection, management, and output. For example, you choose the length of your projection period by using the CYCLE and the YEAR options. The YEAR option determines the interval at which STEMS will stop to both show the growth of a plot and, if you choose, to manage the plot. The CYCLE option sets the number of these intervals. In figure 3, five output cycles of 10 years per cycle create a 50-year projection period. Two other option examples are:

1. Whether or not TABL will be used. Instructions are given for TGPS to create a standard output file to be used by TABL for producing printed detailed summaries (fig. 3, STAN). If this option is not taken, information will not be stored to run TABL.
2. Whether or not to apply management, and if so, when: before, after, in the middle of each cycle, or at year(s) you set for cutting (fig. 3, MANA).

Interactive and Batch Versions

Two versions of STEMS can be used, interactive and batch. The interactive version is typically used for modeling a few stands to prepare for a batch run or to compare the effects of different prescriptions or marking rules. This version allows you to make choices throughout the run. Here, not only are the user options initially presented, but they later reappear at the beginning of each growth cycle. You, therefore, have more than one opportunity to change these options and shape the STEMS run.

[1] *For variable-radius plots, the following equation is used to calculate the expansion factor;*

$$BAF/.005454n[1/D^2]$$

where: BAF = *basal area factor*
n = *number of sample points*
D = *individual tree diameter*

```
(CYCL)    5.   NUMBER OF OUTPUT CYCLES.
(YEAR)   10.   NUMBER OF YEARS/CYCLE.
(STAN)    1.   STANDARD OUTPUT FILE FOR PROGRAM TABL, 0=NOT USED, 1=USED
(MANA)    3.   MANAGEMENT OPTION, 1=FIRST YEAR,2=MID-POINT,3=LAST YEAR,4=USER SPT.
```

Figure 3.—*User option examples.*

The batch version is used when you want to process many plots quickly. You choose all the options before the run begins, and the plots are processed successively and continuously. Unlike the interactive version, you cannot make changes or experiment.

GROWTH PROJECTIONS

Once you enter the tree list and select the initial options, STEMS begins annually projecting the stand growth. For each tree on the list it simulates potential tree growth, tree growth modifiers, and tree mortality based on biological principles (Belcher *et al.* 1982) (fig. 4). At the end of each growth cycle, the system updates and reports plot conditions in terms of basal area, number of trees per acre, average d.b.h., and volume, as shown for plot 12C in figure 5.

STAND GROWTH = POTENTIAL TREE GROWTH + TREE GROWTH MODIFIER + TREE MORTALITY

Figure 4.—*Components in STEMS growth projections.*

Potential Tree Growth

Growth is first projected by calculating the potential growth for each tree on the list as if it were freely growing without competition from neighboring trees.

SUMMARY OF INITIAL CONDITIONS.

SHORT REPORT FOR PLOT=12C YEAR= 1985 CYCLE= 0 SITE INDEX= 45 AGE= 55

SPECIES GP.	#TREES	#DEAD TREES	#CUT TREES	#LIVE TREES	#LIVE TREE/AC	BA/ ACRE	AVG DBH	VOLUME IN CUBIC FEET.
WH. SPRUCE	1	0	0	1	7.6	4.6	10.5	95.20
BALSAM FIR	1	0	0	1	3.3	1.3	8.6	22.65
N.WH.CEDAR	4	0	0	4	25.7	14.2	10.0	215.04
BLK.GR.ASH	8	0	0	8	59.1	19.3	7.3	268.15
ELM	2	0	0	2	17.0	9.2	9.9	154.87
QUAK.ASPEN	1	0	0	1	5.4	4.3	12.1	84.88
TOTAL	17	0	0	17	118.1	53.0	8.7	840.81

SUMMARY FOR END OF CYCLE.

SHORT REPORT FOR PLOT=12C YEAR= 2025 CYCLE= 4 SITE INDEX= 45 AGE= 95

SPECIES GP.	#TREES	#DEAD TREES	#CUT TREES	#LIVE TREES	#LIVE TREE/AC	BA/ ACRE	AVG DBH	VOLUME IN CUBIC FEET.
WH. SPRUCE	1	0	0	1	7.6	10.9	16.2	290.85
BALSAM FIR	1	0	0	1	3.3	4.6	16.0	120.74
N.WH.CEDAR	4	1	0	3	19.2	26.9	16.0	472.44
BLK.GR.ASH	8	1	0	7	49.2	35.6	11.0	599.79
ELM	2	1	0	1	10.0	11.5	14.5	212.76
QUAK.ASPEN	1	1	0	0	0	0	0	0
TOTAL	17	4	0	13	89.3	89.5	13.1	1696.59

Figure 5.—*Reports before and after STEMS "grows" plot 12C.*

The potential diameter growth is calculated with tree crown ratio, initial d.b.h., species, and site index. Diameter is used as the basic tree measurement for growth projection because it reflects the entire tree's growth and is easily obtained.

The tree crown, as the site of photosynthesis, influences current growth. Field-measured crown ratios give the most accurate growth projections. However, if you have not measured crown ratio for your plot, STEMS will produce its own estimates of crown ratio based on d.b.h. and basal area.

Growth Modifier

To make projections realistic for trees that grow in forests and not in the open, the estimated potential growth is modified by considering each tree as a member of a plant community that shares sunlight, water, and nutrients.

A modifying factor is calculated using plot basal area, average plot diameter, and tree diameter. This factor is combined with potential growth to predict the "realized" diameter growth for each tree entry and the trees it represents.

Tree Mortality

To estimate change in a forest, both the growth and death of each tree in the plot need to be predicted. Trees usually die when they become unable to compete for sunlight, water, and nutrients. STEMS predicts this competition-related mortality. Occasionally catastrophes, including diseases, insects, and winds, cause many trees or an entire stand to die in a short time. STEMS does not predict this mortality.

The probability that a tree will die in a given year is calculated using the tree's current d.b.h. and a measure of its vigor. In the Lake States, this vigor is measured by annual diameter growth rate; and in the Central States it is measured by the basal area of trees larger than the sample tree. You have two options for assigning this mortality function to a tree: probabilistic and deterministic mortality (appendix).

TIMBER MANAGEMENT

TGPS projects tree growth and mortality for each year of the projection period. The interactive system stops at each cycle and if you decide to "manage" the plot, silvicultural prescriptions are made. Plots prescribed for harvests and thinnings are "marked" and "cut". Harvested plots are then regenerated. If you decide not to use the management option, STEMS "grows" the plot through the projection period without management (fig. 6).

Plots are "managed" with silvicultural prescriptions selected on the basis of cover type. Plot cover type is determined from the species or group of species with the greatest basal area. For each cover type, STEMS uses a management key based on silvicultural guides published by the North Central Forest Experiment Station.

STEMS uses assumptions that greatly simplify the integration of complex forest factors (i.e., soil, insects, disease, competing vegetation, and land use). For example, STEMS assumes that: trees are uniformly spaced and that shrubs and herbs are unimportant to tree growth and mortality. Other assumptions are made for each cover type. Thus STEMS management prescriptions can only be used as guidelines. Although you can manipulate prescriptions to reflect stand conditions, you will probably need to modify and adjust these prescriptions before actually applying them to your stands.

Cut prescriptions are put into "action" with marking rules. After management, STEMS produces an updated summary of the plot that includes number of live, cut, and dead trees in the plot; live trees per acre; basal area per acre; d.b.h.; and volume (fig. 7). Volume can be calculated in board feet, cords, cubic feet in saw logs, cubic feet, or biomass in cubic feet.

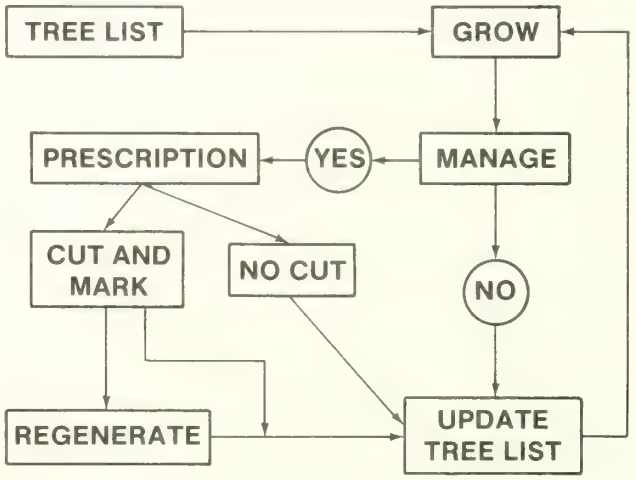

Figure 6.—*STEMS management.*

```
==== MANAGEMENT ====                                    YEAR=2025
                                                        MANAGEMENT GUIDE
COVERTYPE: B.ASH-ELM-MAPLE                              LOWLAND HDWD.
ACTION: CLEARCUT                                        SI = 45
                                                        AGE = 95
                                                        TREES/AC = 89

NUMBER OF TREES CUT=   89.3  BASAL AREA CUT=   89.5 SQUARE FEET/AC.
VOLUME CUT=     1696.6 CUBIC FEET.


PLOT CONDITIONS AFTER MANAGEMENT.
+++++++ ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
SHORT REPORT FOR PLOT=12C  YEAR= 2025  CYCLE=  4  SITE INDEX=  45  AGE=  0

                #TREES #DEAD #CUT  #LIVE   #LIVE     BA/    AVG    VOLUME IN
SPECIES GP.              TREES TREES TREES  TREE/AC  ACRE   DBH    CUBIC FEET.
WH. SPRUCE          1      0     1     0        0     0      0          0
BALSAM FIR          1      0     1     0        0     0      0          0
N.WH.CEDAR          4      1     3     0        0     0      0          0
BLK.GR.ASH          8      1     7     0        0     0      0          0
ELM                 2      1     1     0        0     0      0          0
QUAK.ASPEN          1      1     0     0        0     0      0          0
-------------------------------------------------------------------------------
TOTAL              17      4    13     0        0     0      0          0
```

Figure 7.—*Update after a clearcut for plot 12C.*

Prescription Standards

STEMS makes management prescriptions for the following forest types:

Lake States

Jack pine	Tamarack
Red pine	Oak-hickory
White pine	Aspen
Spruce-fir	Paper birch
Black spruce	Lowland hardwoods
Mixed swamp conifers	Northern hardwoods
Northern white-cedar	Understocked

Central States

Elm-ash-cottonwood	Shortleaf pine
Pin oak	Northern hardwood
Oak-hickory	Eastern redcedar

The prescriptions come from management keys that are like roads with a series of intersections. At each intersection, STEMS decides which way to turn (or how to manage your plot) by comparing the plot's characteristics with values given by the management key. These values are called critical values. In figure 8, the critical values for jack pine are 60 feet for site index and 65 and 50 years for age.

To understand management-by-key, imagine you are managing this plot:

Cover Type - Lake States Lowland Hardwood
Site Index - 60
Age - 75
Basal Area - 80 square feet per acre

Without your intervention, STEMS assigns the Lake States lowland hardwood management key based on the species composition of the plot. Using this key, a prescription is obtained by first comparing

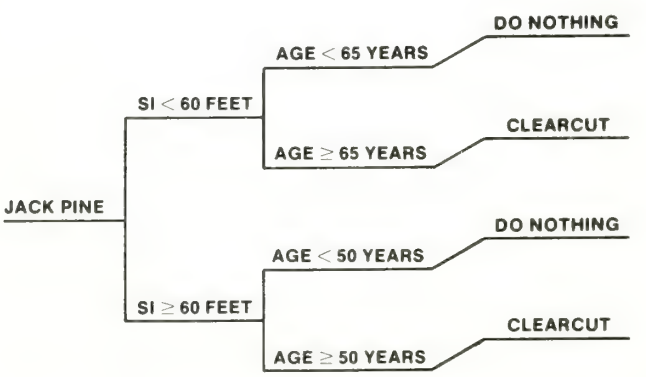

Figure 8.—*Jack pine management key.*

the plot site index of 60 with the value at the first intersection, 55 (fig. 9). Because the site index is greater than 55, the lower path is taken. Next, the plot age of 75 years is compared with the value at the next intersection, 90 years. The top route is selected because the plot age is less than 90. Finally, the plot basal area of 80 square feet per acre is less than 110, so the prescription is "do nothing".

Using the "management-by-key" method, STEMS automatically manages your plot according to its built-in prescriptions.

If you choose to "manage" the plot differently than the keys do, the interactive version of STEMS can be modified to alter its management prescriptions. You can change prescriptions in two ways:

1. Use a different key for a different cover type instead of accepting the assigned management key for your cover type, or
2. change the critical values within the assigned key. To make the key more general, the critical values are replaced with symbols that indicate they may be changed (fig.10).

As an example of this first method, suppose your plot is part of a stand that has been underplanted with spruce, and your stand objective is conifer conversion. You decide the lowland hardwood key is inappropriate. Before the management subsystem begins, you are given the option to accept the use of the lowland hardwood key or choose an alternative. In this instance you would select the spruce-fir key because it would probably give the most suitable prescription for your underplanted stand.

Consider the second method: assume that the best cover type for your plot is lowland hardwood, but you would like to see a different treatment prescribed than offered by the lowland hardwood key. For example, you would like to know how a shelterwood cut

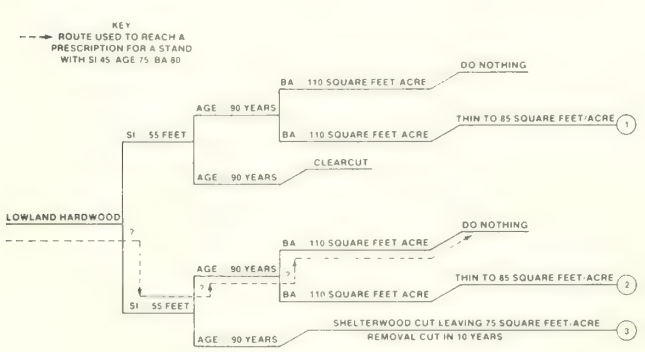

Figure 9.—*Example of how a Lake States lowland hardwood key is used by STEMS.*

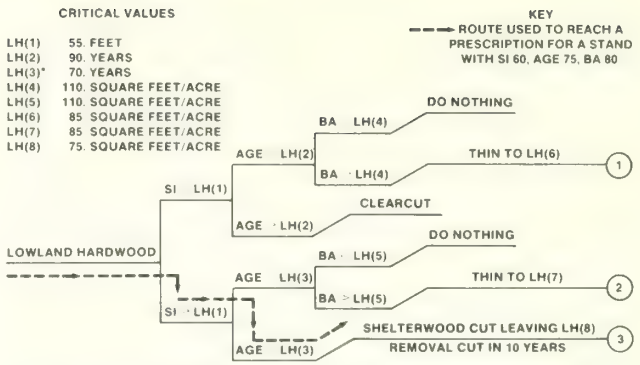

Figure 10.—*Modified Lake States lowland hardwood key.*

would affect your plot. To obtain a different prescription, you modify the Lake States lowland hardwood key (fig. 10). In this example, you could change the critical value LH(3) from 90 to 70 years. Comparing the plot site index 60 with the critical value of 55 (LH(1)), you again take the lower path. Next, the stand's age (75) is greater than 70 so this time the lower path is selected and the prescription is "shelterwood cut". This critical value is changed with an option that asks the user if critical values are to be changed and what the changes are (fig. 11).

Because of the ability to change critical values, many other lowland hardwood prescriptions can be produced with this key. Flexibility, however, is limited because the structure of these keys cannot be changed. This means intersections are not added and other stand characteristics cannot be substituted. For instance, if a Lake States lowland hardwood silvicultural guideline recommends different prescriptions for three ranges of site index, this key in figure 10 cannot be used. Neither can a guideline be used that makes a prescription based on average diameter. In these cases, a new key must be constructed and programmed from the silvicultural guidelines.

Marking

When a cut is prescribed for a plot, STEMS "marks" and "cuts" the trees. For a clearcut prescription, all trees are cut. For thinnings and shelterwood cuts, STEMS simulates marking rules. Unlike the critical values, the marking rules cannot be changed during the STEMS interactive version run. However, with minimal programming ability, they can be changed before the run begins.

For each management key, different marking rules rank trees to be cut. One example of marking rules for thinning a Lake States lowland hardwood stand is to mark in the following order:

(1) low-quality trees,

```
THE CURRENT CRITICAL VALUES ARE:
INDEX      1        2        3        4        5        6        7        8
VALUE    55.0     90.0     90.0    100.0    110.0    85.00    85.00    75.00

ENTER THE INDEX AND VALUE FOR THE CRITICAL VALUE WHICH YOU WISH TO CHANGE.
PRESS  (CR)  WHEN ALL THE CHANGES ARE MADE.

ENTER INDEX AND VALUE:

? 3 70

THE CURRENT CRITICAL VALUES ARE:
INDEX      1        2        3        4        5        6        7        8
VALUE    55.0     90.0     70.0    100.0    110.0    85.00    85.00    75.00
```

Figure 11.—*Changing critical values for management.*

(2) elms from above (with the largest diameters cut first),
(3) specified undesirable species from below (cut the smallest diameter trees first),
(4) specified desirable species from below.

These rules follow in order until the cutting limit, set by the prescription, is obtained. If the prescription was to thin to 90 BA and this limit was obtained after going through step 1 and halfway into step 2, the remainder of the marking rule steps would not be used.

The Lake States management keys, their objectives and assumptions; marking rules; and further STEMS timber management information can be found in *Simulating Timber Management in Lake State Forests*, Brand (1981). For Central States management information, contact the North Central Forest Experiment Station.

REGENERATION

STEMS simulates regeneration that occurs immediately after a plot has been cut. The system does not consider regeneration that grows under a stand each year or that fills in openings created by natural death or thinnings. These types of regeneration will be incorporated into STEMS in the future.

A cut is regenerated by STEMS when it places new trees on a tree list. This happens after TGPS has made a clearcut, shelterwood cut, or strip clearcut. By default, the age at which the regenerated plot enters the growth projection program is 15 years, but you can change this to any age.

The regenerated plot is characterized by the following critical values: species group, number of trees per acre, average d.b.h., and standard deviation (fig. 12). You can supply these regeneration values or, for most species, STEMS will use its default values.

Default values are based on a series of regeneration plots located in Lake and Central States national forests. Because the STEMS regeneration data base is not extensive, these values are only starting points. From them, STEMS will provide a general picture of the type of stand that will come back after a harvest. If you have a better idea of your plot's characteristics, you can enter them in lieu of STEMS's default values.

The default characteristics of the regenerated plot are based on the cover type of the harvested plot, the type of cut used, and cover type characteristics that include basal area and site index. In figure 13, the

```
THE REGENERATION CRITICAL VALUES SELECTED ARE:     NUMBER OF SPECIES GROUPS= 2
SP.GP.#   #TREES/AC   AVG DBH   STD.DEV.
    5.        800.0       2.0         .2
    4.        400.0       1.0         .1

PRESS (CR) TO ACCEPT THESE VALUES OR 1 TO RE-ENTER THEM.
```

Figure 12.—*Regeneration critical values.*

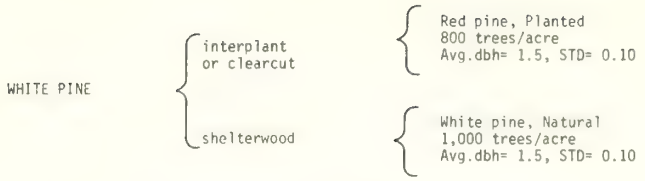

Figure 13.—*White pine regeneration as determined by previous management.*

white pine regeneration values are determined by previous management. If the plot had been interplanted or clearcut, a red pine plantation would result with 800 trees/acre and an average d.b.h. of 1.5 inches at 15 years of age. Had the plot been shelterwood cut, the regenerated plot would be a 15-year-old natural white pine plot with 1,000 trees per acre and an average d.b.h. of 1.5 inches.

OUTPUT

The output from STEMS summarizes growth projections, management, and regeneration in written tables. Summaries can be obtained from both TGPS and TABL. In the interactive version, brief TGPS summaries, produced at the beginning of each growth cycle, report stand conditions and volume for the plot (figs. 5 and 14). After STEMS presents the summary tables, you can change the user options such as the number and length of growth cycles, when to manage, and units for volume(fig. 3). When the batch version is used, however, no output is produced by TGPS and changes cannot be made.

TABL is only one of many ways STEMS can be used to summarize data. It is offered as a default summary program or a place to start when designing a summary program. TABL was made separate from

SHORT REPORT FOR PLOT= 12C YEAR=1985 CYCLE= 1 COVERTYPE= 71
MANAGEMENT GUIDE= 0 SITE INDEX= 45 AGE=55

SPECIES GP.	#TREES	#DEAD TREES	#CUT TREES	#LIVE TREES	#LIVE TREE/AC	BA/ ACRE	AVG DBH	VOLUME IN CUBIC FEET.
WH. SPRUCE	1	0	0	1	7.6	4.6	10.5	95.20
BALSAM FIR	1	0	0	1	3.3	1.3	8.6	23.53
N.WH.CEDAR	4	0	0	4	25.7	14.2	10.0	215.04
BLK.GR.ASH	8	0	0	8	59.1	19.3	7.3	268.15
ELM	2	0	0	2	17.0	9.2	9.9	148.95
QUAK.ASPEN	1	0	0	1	5.4	4.3	12.1	84.88
TOTAL	17	0	0	17	118.1	53.0	8.7	835.76

NUMBER OF LIVE TREES/AC BY DIAMETER CLASS.

	0---	2---	4---	6---	8---	10---	12---	14---	16---	18---	20---	22---	24
WH.SPRUCE	0.	0.	0.	0.	0.	8.	0.	0.	0.	0.	0.	0.	0.
BALSAM FIR	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.
N.WH.CEDAR	0.	0.	0.	0.	11.	15.	0.	0.	0.	0.	0.	0.	0.
BLK.GR.ASH	0.	10.	10.	16.	10.	14.	0.	0.	0.	0.	0.	0.	0.
ELM	0.	0.	0.	0.	10.	7.	0.	0.	0.	0.	0.	0.	0.
QUAK.ASPEN	0.	0.	0.	0.	0.	0.	5.	0.	0.	0.	0.	0.	0.
TOTAL	0.	10.	10.	16.	34.	43.	5.	0.	0.	0.	0.	0.	0.

VOLUME OF LIVE TREES/AC BY DIAMETER CLASS.

	0---	2---	4---	6---	8---	10---	12---	14---	16---	18---	20---	22---	24
WH.SPRUCE	0.	0.	0.	0.	0.	95.	0.	0.	0.	0.	0.	0.	0.
BALSAM FIR	0.	0.	0.	0.	24.	0.	0.	0.	0.	0.	0.	0.	0.
N.WH.CEDAR	0.	0.	0.	0.	76.	139.	0.	0.	0.	0.	0.	0.	0.
BLK.GR.ASH	0.	0.	0.	32.	86.	150.	0.	0.	0.	0.	0.	0.	0.
ELM	0.	0.	0.	0.	72.	77.	0.	0.	0.	0.	0.	0.	0.
QUAK.ASPEN	0.	0.	0.	0.	0.	0.	85.	0.	0.	0.	0.	0.	0.
TOTAL	0.	0.	0.	32.	258.	461.	85.	0.	0.	0.	0.	0.	0.

Figure 14.—*Brief TGPS summary.*

TGPS so, with some background in computer programming, you can create your own summary FORTRAN program and use it with STEMS. This is done with a "dummy" routine called OUTUR (Belcher 1981). For example, you can program OUTUR to produce a graphics plot of diameter distribution of northern hardwoods at 10-year intervals.

TABL makes final, detailed summaries of STEMS runs in both the interactive and batch versions. With user options, presented initially in the TABL run, you decide the type of table STEMS will produce. You can choose any or all of the following four types of tables (fig. 15):

1.—Single plot summaries for one growth cycle
2.—Single plot summaries for all growth cycles
3.—Cycle summaries for all plots and one cycle
4.—Grand summaries for all plots and all cycles

Two of the options you specify in formulating TABL are diameter class limits and units of volume i.e., no volume, biomass in cubic feet, cubic feet, board feet, cubic feet in saw logs, and cords.

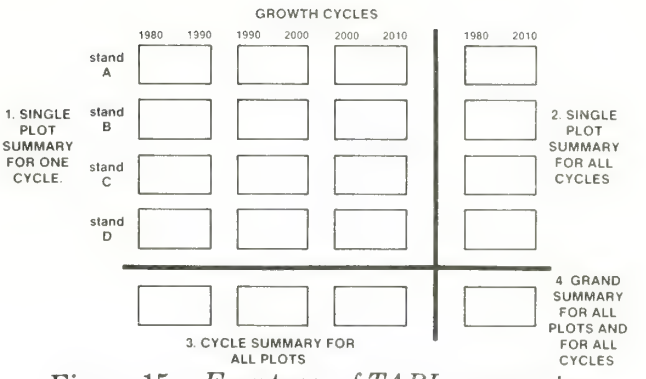

Figure 15.—*Four types of TABL summaries.*

Each TABL summary is divided into three sections (fig. 16) The first section identifies the plot and provides information such as cover type, initial age, site index, current age, and average stand diameter. The second section categorizes the number of trees per acre and basal area of the stand into species groups and user-specified diameter class. The final section shows volume of growth components. This summarizes initial volume, growth that remained in

1. PLOT SUMMARY TABLE FOR CYCLE 2 OF 4

COVERTYPE	B.ASH-ELM-MA	PLOT SITE INDEX	45
INITIAL YEAR	2005	CURRENT YEAR	2025
INITIAL AGE	75	CURRENT AGE	95
PROBABILISTIC MORTALITY USED.		AVERAGE STAND DIAMETER (INCHES)	13.1

MEAN ANNUAL INCREMENT ***** CORDS(79 CU.FT.) PER ACRE PER YEAR.

MANAGEMENT ACTION IN YEAR 2005 WAS: DO NOTHING

PROPERTY HAWK PLOT 12C

PLOT AREA EXPANSION FACTOR 1.
ALL VALUES ARE ON A PER ACRE BASIS.
ALL VOLUMES ARE IN CORDS(79 CU.FT.)
INGROWTH DIAMETER: TREES AND BA= 5.0 INCHES.

INGROWTH DIAMETER: VOLUMES = 5.0 INCHES.

2. NUMBER OF TREES AND BASAL AREA INFORMATION.

SPECIES GROUP	DIAMETER CLASS	...INITIAL.. TREES	BA	...NON-ING... TREES	BA	..INGROWTH.. TREES	BA	..MORTALITY. TREES	BA	..REMOVALS.. TREES	BA	...CURRENT.. TREES	BA	GROWTH (BA)
WH. SPRUCE	0.0- 5.0	0	0	0	0	0	0	0	0	0	0	0	0	
	5.0-11.0	0	0	0	0	0	0	0	0	0	0	0	0	
	11.0- +	8.	8.0	8.	10.9	0	0	0	0	0	0	8.	10.9	2.9
	TOTAL	8.	8.0	8.	10.9	0	0	0	0	0	0	8.	10.9	2.9

3. VOLUME BY COMPONENTS OF GROWTH. CORDS(79 CU.FT.)

SPECIES GROUP	DIAMETER CLASS	INITIAL VOLUME	GROWTH ON NON-ING	GROWTH ON INGROWTH	GROWTH ON INGROWTH	OTHER GROWTH	GROSS GROWTH	MORTALITY	NET GROWTH	REMOVALS	NET INC. INVENTORY	CURRENT VOLUME
WH. SPRUCE	0.0- 5.0	0	0	0	0	0	0	0	0	0	0	0
	5.0-11.0	0	0	0	0	0	0	0	0	0	0	0
	11.0- +	3408.2	6.3	0	0	0	6.3	0	6.3	0	6.3	3414.5
	TOTAL	3408.2	6.3	0	0	0	6.3	0	6.3	0	6.3	3414.5

Figure 16.—*Three sections of TABL cycle summary for one species of plot 12C.*

one diameter class (NON-ING), growth from one diameter class to another in the period represented by the table (INGROWTH), other growth, gross growth, mortality, net growth, removals, net increase in inventory, and current volume.

APPLICATIONS

As a mainframe computer system, STEMS has the capacity to evaluate large numbers of plots successively; therefore, statewide and regionwide analyses can be quickly made at reasonable costs. The system's flexibility allows you to tailor output to fit your needs. STEMS is used for forest planning, management, education, and research.

For example, natural resource planning in Wisconsin by State and regional public agencies, as well as by private companies and organizations, has been done on the basis of a 1980 Wisconsin timber update that implemented STEMS. This inventory was conducted by foresters at the North Central Forest Experiment Station who first used aerial photographs to determine if permanent plots had or had not been disturbed since the last inventory in 1968. Then, on the basis of the 1968 inventory, STEMS updated the forest growth on the undisturbed plots while field crews inventoried the disturbed plots.

Similar inventories have been done for national, state, and private industry forests in the Lake States. One timber company uses STEMS data to help calculate yearly capital gains during years when field inventories are not conducted and to analyze alternative management schemes for long-range planning.

The management routine's wide range of alternatives, combined with the growth routine, allows planners to compare future stands shaped by different silvicultural treatments. Timber yields can be predicted with management at various intensities or without management.

In addition to being a planning and management tool, STEMS provides realistic and dynamic means for educators to teach forest growth and management to students. Also, researchers can use STEMS to simulate forest growth experiments, many of which would be impractical or impossible to conduct in the field.

SUMMARY

As a growth and yield model, STEMS simulates tree growth annually. Plot growth is based on potential tree growth, a growth modifier, and mortality. A management routine selects plot prescriptions based on cover type and silvicultural guides. Plots are "marked" for cut prescriptions; and after harvest cuts, plots are "regenerated".

The STEMS user supplies the system with a tree list representing an actual or hypothetical plot. He or she chooses options that tailor the STEMS run. STEMS output is used to update forest inventories, project yields, and evaluate silvicultural responses to alternative prescriptions. The system is a valuable tool for forest planning, management, education, and research.

LITERATURE CITED

Belcher, David M. The user's guide to STEMS (Stand and Tree Evaluation and Modeling System). Gen. Tech. Rep. NC-70. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1981. 49 p.

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APPENDIX

MORTALITY

Probabilistic (Lumpy) Mortality: A tree and all trees per acre it represents live or die as a group. (Lumps of mortality occur periodically (fig. 17)).

Deterministic (Smooth) Mortality: A tree's per acre expansion factor is annually reduced in proportion to the mortality rate. (Small amounts of mortality occur annually, smoothing out stand growth over time (fig. 17)).

Example: Consider the situation where a tree list includes a tree with a 7 inch d.b.h. and a per acre expansion factor of 10 (i.e., it represents ten 7-inch trees per acre). If the probability of mortality for the tree was 0.10 in a given year, then:

A. With probabilistic mortality, there is a 1 in 10 chance that all ten 7-inch d.b.h. trees will die that year. If the 1 in 10 chance occurs, all 10 trees per acre are classified as dead for that year (fig. 18).

B. With deterministic mortality, the tree expansion

factor is reduced to 90 percent of its original value. There would be nine 7-inch live trees and one 7-inch dead tree (fig. 18).

Probabilistic vs. Deterministic Mortality

Because probabilistic mortality uses fewer calculations, it costs less to use than deterministic mortality. When the probabilistic mortality method "kills" trees in lumps, growth computations for the remaining projection period are unnecessary for the 'dead' tree list entry. When deterministic mortality is applied, however, each tree on the list is retained, and the tree expansion factor is diminished by fractions.

For small amounts of data, deterministic mortality better imitates nature by its smooth reduction of growth than does probabilistic mortality. For large amounts of data, however, with many plots and long projection periods, such as found in statewide inventories, the "lumpiness" of probabilistic mortality is averaged, resulting in a realistic mortality prediction.

AFTERWORD

STEMS is continually being refined and expanded to better simulate the natural world and to meet its users' needs. One expansion is a microcomputer version, TWIGS. This program, unlike STEMS, cannot evaluate the growth and management of many stands successively. TWIGS, however, is ideal for stand by stand analyses. It also examines the costs and revenues of stand management.

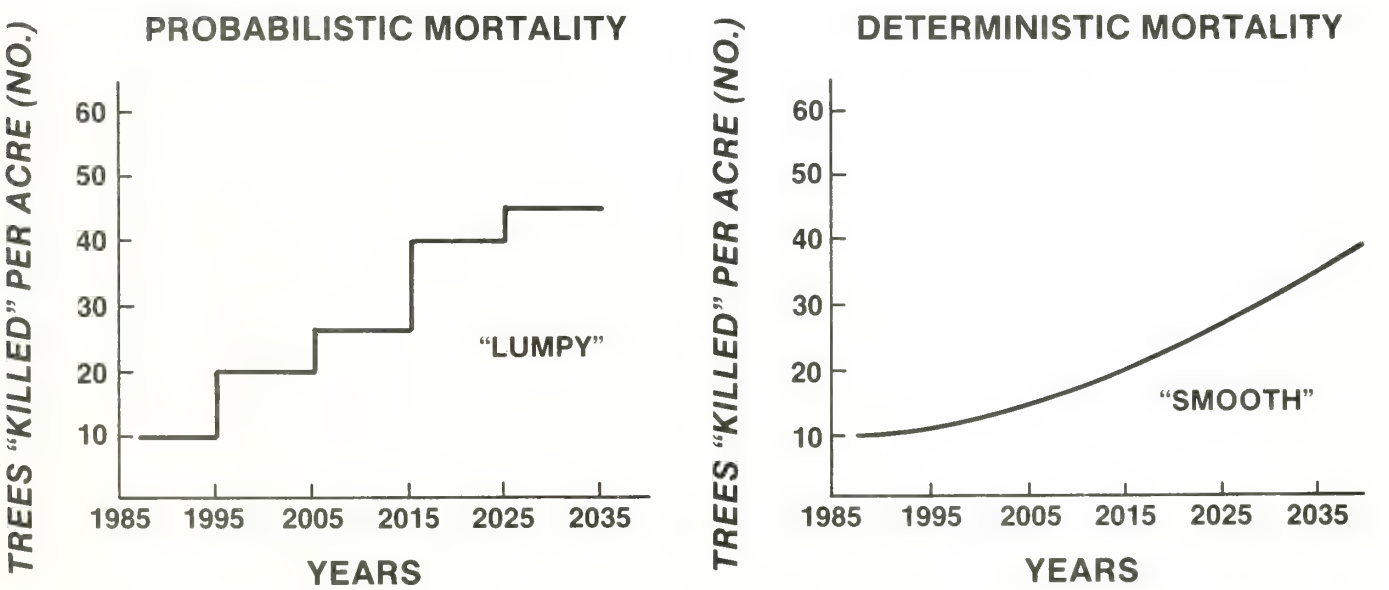

Figure 17.—*"Lumpy" and "smooth" mortality.*

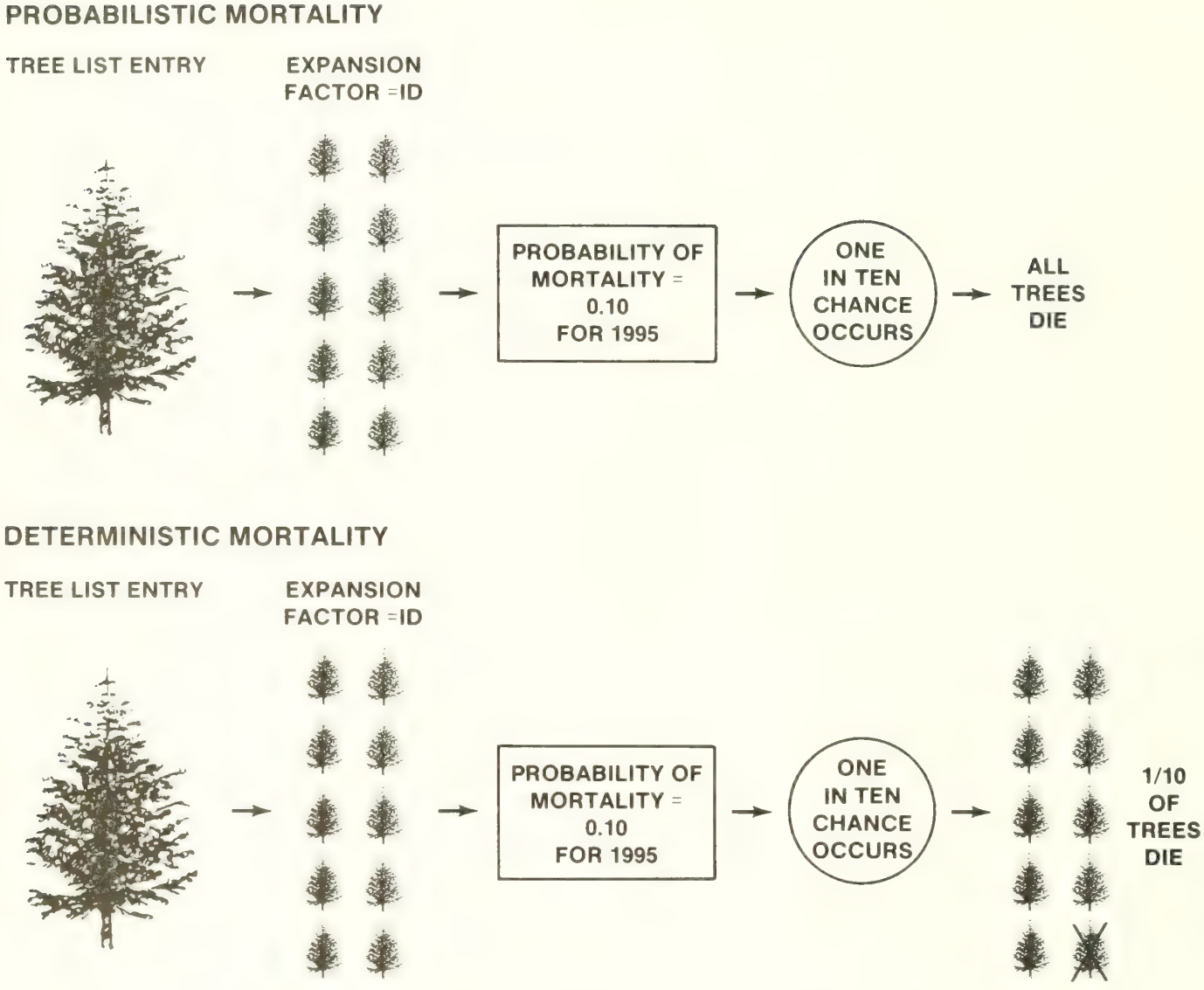

Figure 18.—*Example of probabilistic and deterministic mortality.*

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984—767-147/10063

Miner, Cynthia L.; Walters, Nancy R.
STEMS: A nontechnical description for foresters. Res. Pap. NC-252. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 12 p.

Explains how STEMS simulates tree growth, mortality, management, and regeneration. Discusses input—including user options and tree lists—output, and applications.

KEY WORDS: Simulation, growth projections, forest modeling, timber management, FORTRAN, individual tree.

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Feller/Bunchers in Plantation Thinnings: Factors Affecting Productivity

Sharon A. Winsauer, James A. Mattson, and Michael A. Thompson

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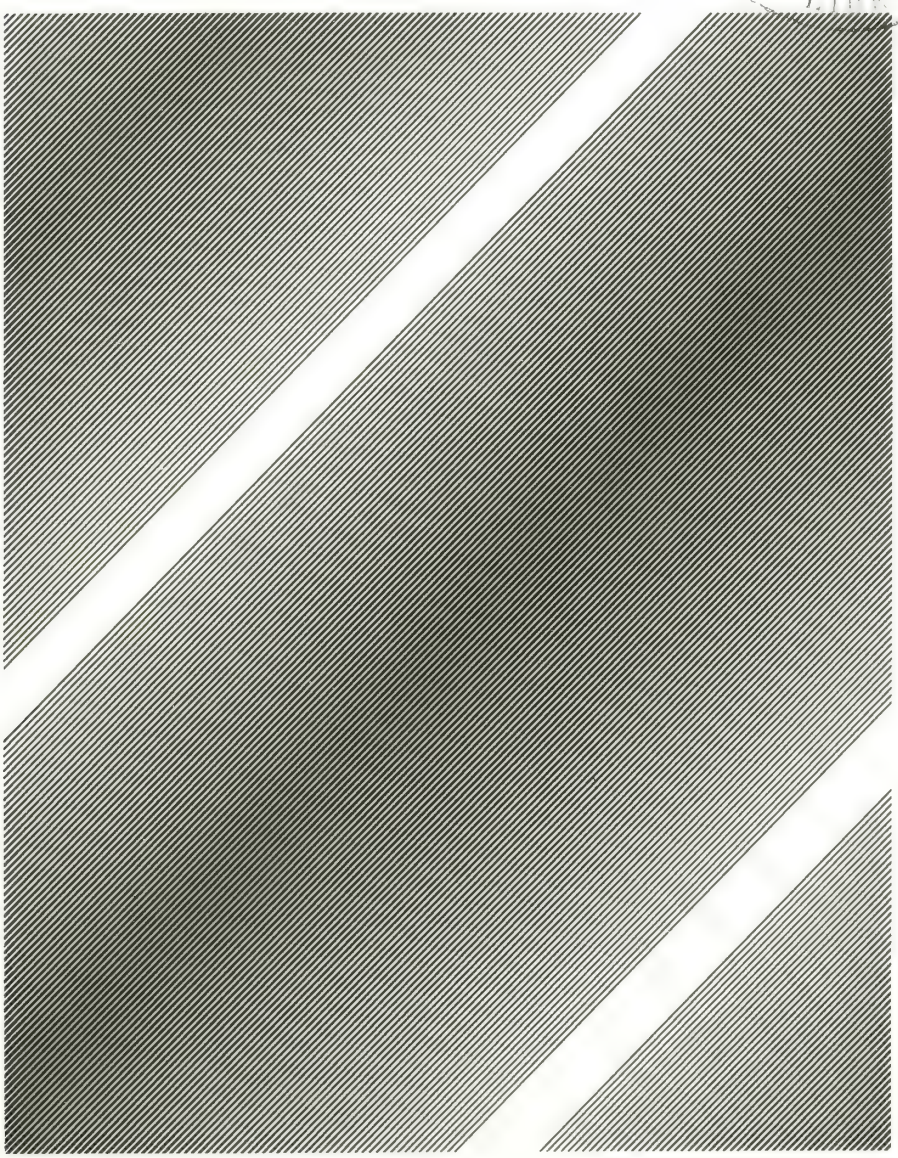

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St. Paul, Minnesota 55108
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CONTENTS

	Page
Stand Characteristics	1
Operational Factors	4
Machine Characteristics	11
Conclusions	14
Literature Cited	15

FELLER/BUNCHERS IN PLANTATION THINNINGS: FACTORS AFFECTING PRODUCTIVITY

Sharon A. Winsauer, *Mathematician,*
James A. Mattson, *Principal Mechanical Engineer,*
and **Michael A. Thompson,** *Associate Engineer,*
Houghton, Michigan

Closely spaced plantations must be thinned early for optimal tree growth, but removing small trees is costly. Harvest costs can be lowered by using highly productive machines, such as feller/bunchers. To identify possible areas for improving design and operation of feller/bunchers, we used computer simulation to study the sensitivity of harvesting productivity to machine and stand characteristics.

Two basic feller/buncher designs were studied: the chassis-mounted and boom-mounted shear types. A feller/buncher with a chassis-mounted shear must drive to each tree and accurately position the shear head. In contrast, a feller/buncher with a boom-mounted shear can reach several trees from one location, thus reducing machine travel in the stand. Because of these operational differences, we used separate simulation models for each machine type (Winsauer 1980, Winsauer and Bradley 1982). The models were written in the simulation language GPSS, General Purpose Simulation System. The computer runs were made on the UNIVAC 1100/80 housed at Michigan Technological University, Houghton, Michigan.

The variables we considered in this investigation were:

1. Stand characteristics:
   Tree spacing
   Average tree diameter at breast height (d.b.h.)
   Basal area (BA)
2. Operational factors:
   Thinning pattern
   Thinning intensity (percent tree removal)
3. Machine characteristics:
   Accumulating capacity of shear
   Average travel speed
   Average shear time
   Average drop time
   Boom travel speed
   Maximum and minimum boom reach

These variables were used as input to the simulation. For each variable we chose a range of values representative of existing equipment and stands. Within this range, we chose a typical value to be used as a standard. Comparison of the model output values—productivity, elemental time, travel distance, and bunch size—formed the basis of the analysis.

STAND CHARACTERISTICS

We limited our investigation to small-diameter plantations of equally spaced softwoods (table 1). We decided not to emphasize a particular species but to consider a generalized "softwood." Height and density values were fixed at representative values, and the

Table 1.—*Initial stand characteristics*

Assumptions		
Species	Softwood (generalized)	
Stand structure	Plantation—square spacings	
Terrain	Flat	
Strip length	100 m	
Tree volume(m^3)	$0.021 + 0.00048 \times$ d.b.h.^{2} (cm)	
(ft^3)	$0.73 + 0.109 \times$ d.b.h.^{2} (in.)	
Tree height (m)	10	
(ft)	33	
Wood density (kg/m^3)	600	
(green basis) (lb/ft^3)	37	
Variables	**Range**	**Base value**
Tree diameter at (cm)	6.0 to 16.0	10.0
breast height (d.b.h.) (in.)	2.4 to 6.3	4.0
Tree spacing (m)	1.0 to 2.5	1.5
(ft)	3.3 to 8.2	5.0
Associated parameters	**Range**	
Stand density (trees/ha)	1,600 to 10,000	
(trees/acre)	648 to 4,050	
Basal area (m^2/ha)	15 to 50	
(ft^2/acre)	65 to 217	

volume equations were developed from combined data of several softwood species (Winsauer and Steinhilb 1980).

We addressed the effects on productivity by varying two major stand characteristics—tree spacing and diameter. An average initial stand diameter was selected for each computer run. To allow for variability in the number of trees the accumulator could hold, the diameter of each tree was randomly assigned during simulation. We used the following distribution to keep the diameters within a range that would be expected in an even-aged plantation:

25 percent—Average diameter minus 2 cm,
50 percent—Average diameter, and
25 percent—Average diameter plus 2 cm.

To study the effect of stand density on harvesting efficiency, we chose a range of initial tree spacings (from 1 to 2.5 m) that correspond to actual plantations. Basal area, stand density, and diameter are interrelated—thus silvicultural considerations determine the actual density-d.b.h. combination that would exist (fig. 1). Tree growth is minimal in very dense stands. Therefore, we assumed that plantations would not be allowed to exceed a basal area (BA) greater than 50 m^2/ha (217 ft^2/acre). We also assumed that stands with a basal area less than 20 m^2/ha (87 ft^2/acre) would not require thinning. Only those spacing/diameter combinations falling between these basal area limits were considered in this analysis.

Effects of Tree Spacing and Stand Diameter on Harvesting Efficiency

Computer runs were made to "harvest" stands at each of four tree spacings (fig. 2). Basal area was held constant at 35 m^2/ha (150 ft^2/acre) for these runs by increasing the average diameter as the trees/hectare decreased. We made runs for both machine types with the other input variables set at base values. As tree spacing increased the number of trees harvested per hour decreased, regardless of the feller/buncher used. Trees per bunch were primarily affected by tree diameter because the accumulator could not collect as many large trees; however some distance effect also was found because at wider spacings it became too far

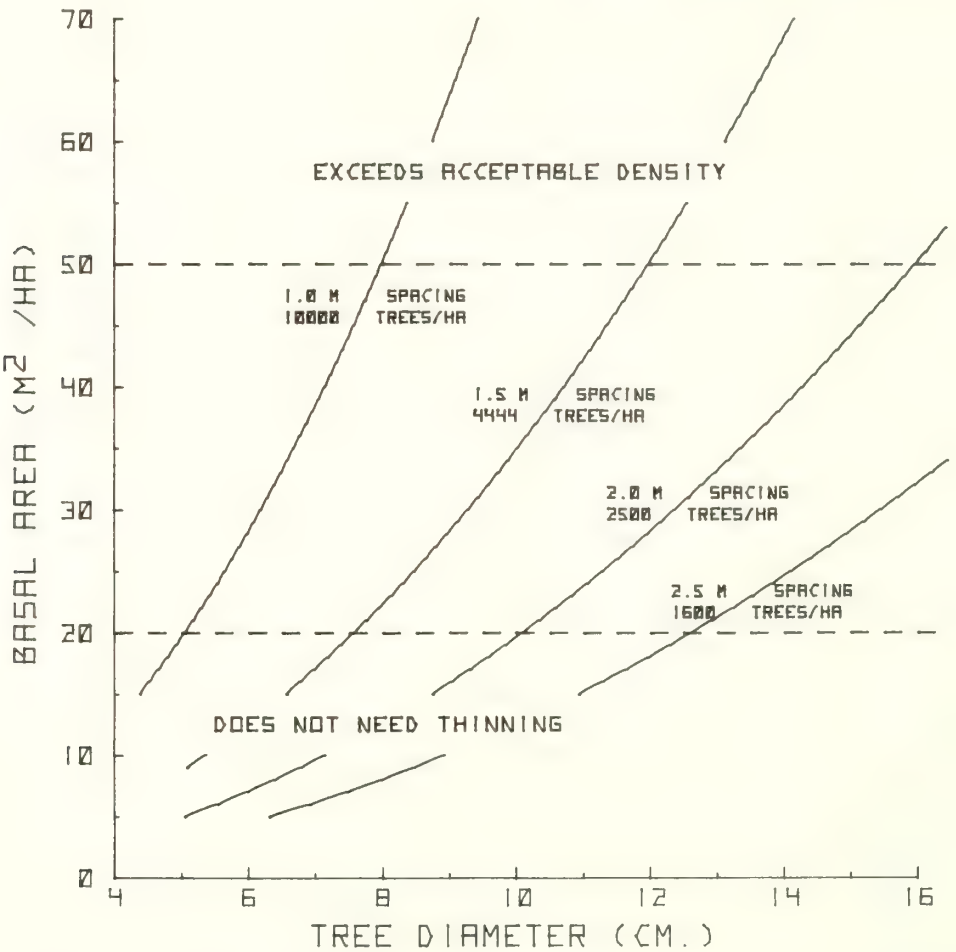


Figure 1.—*Basal area for a generalized plantation as a function of diameter and spacings.*

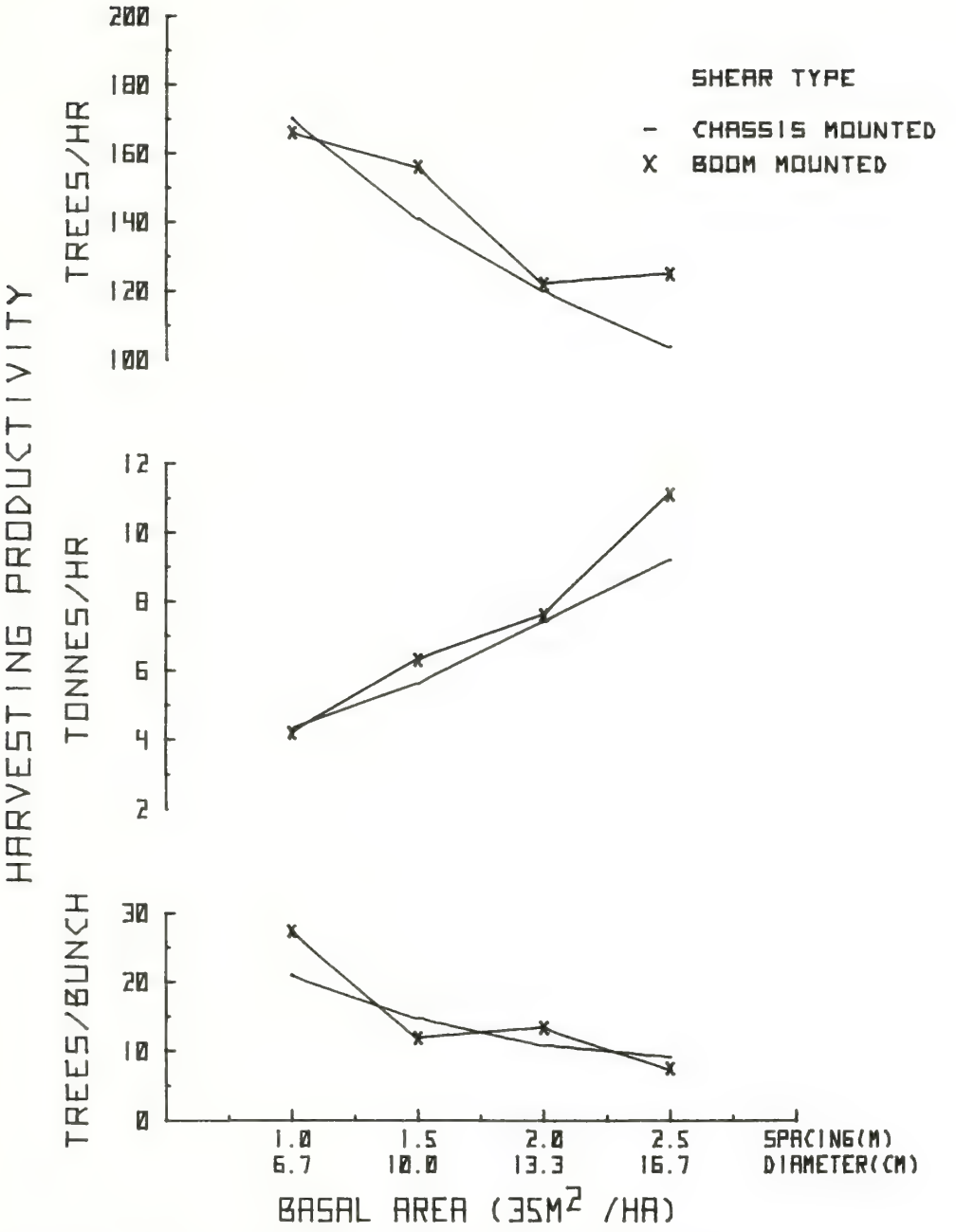


Figure 2.—*Effects of diameter and spacing on harvesting productivity.*

to travel or reach back to increase bunch size. But larger tree volumes more than compensated for the decrease in trees/hour and resulted in greater net productivity (tonnes/hour) and bunch sizes (tonnes/bunch).

We found that the boom-mounted shear was more efficient at some spacings than the fixed shear. The productivity of the two machines was almost identical at the 1.0- and 2.0-m spacings, but when tree spacings were 1.5 and 2.5 m the boom-mounted shear was 10 to 20 percent more productive than the fixed-shear machine. This was caused by the combination of strip-only thinning and the equal tree spacing in the plantation. In the 1.5- and 2.5-m plantations the previous bunch often fell just out of reach of the 10-m boom under consideration so that a new bunch had to be started. This resulted in smaller bunches dropped closer to the machine, decreasing boom swing time and increasing productivity. Although it would not be as distinct in a real harvest, a similar boom reach-spacing effect would be seen that would increase feller productivity at the expense of smaller bunch size and lower skidder production.

OPERATIONAL FACTORS

Operational factors define harvesting methods and the stand/machine interactions (table 2). They cannot be as neatly quantified as the stand and machine characteristics.

For most efficient skidding, trees should be collected into bunches of optimal size for the specific skidder (Bradley 1984). Small, low horsepower machines would be used in these stands, so the optimal skid load was set at 200 cm total diameter—that would be 33 6-cm diameter trees or from 12 to 13 16-cm diameter trees or equivalent, approximately 1 metric tonne.

However, it may not be feasible for the feller/bunchers to assemble the optimal skid load. It is impractical for the chassis-mounted shear type to back up more than two tree lengths (20 m) just to increase the skid bunch, and the machine with a boom-mounted shear will not back up. It will add to the bunch only if it is within reach from its current location.

Thinning pattern was the major operational factor considered in this analysis. Removing strips of trees is probably the most economical treatment but leaves uneven stand density with both silvicultural and aesthetic problems. At the other end of the scale, a selection thinning may be the most desirable but the least practical. In dense stands, machine maneuverability is limited, resulting in low production and high cost. Strip thinning with some thinning of the area between strips is an intermediate option with several possible variations. We confined our investigation to strip-only thinning and to strips with a herringbone or diagonal thinning pattern between strips.

The proportion of trees removed in a thinning depends upon initial stand density/spacing. For the stands with basal area of 35 m^2/ha (150 ft^2/acre) or greater, it may be desirable to remove up to one-half the trees to achieve maximum growth and extend the time until another thinning is necessary. Stands with a basal area of 20 m^2/ha (85 ft^2/acre) are on the lower limit of needing thinning; removing one-fourth of the trees will give them sufficient room to grow.

Thinning intensities of 25, 33, and 50 percent can be achieved by cutting a strip of a single row and leaving three, two, or one uncut rows between or by cutting double rows and leaving six, four, or two, respectively. Removing single rows will result in more even tree distribution than removing double rows. However, in the stands with 1.5 meter spacing or less, removing double rows would be necessary for maneuvering even small machines (fig. 3). Machine sizes used in this study were chosen to cover the range of the smaller fellers currently available.

Table 2.—*Operational factors*

Assumptions		
Chassis-mounted shear:		
Feller must move to each tree to fell it.		
To reach a tree outside the strip, it must back up an equal distance for maneuvering.		
All felled trees will be laid in the strip. The feller will back up, drop the trees, and drive over them.		
Maximum distance the feller will back up to add to a bunch is 20 m (65 feet).		
Boom-mounted shear:		
Feller will not back up.		
Feller swings trees and drops them behind machine in strip.		
Machine does not leave strip.		
Desired bunch size for economical skidding		
(sum of tree diameters)	(cm)	200
	(in.)	80
Variables	**Range**	
Thinning pattern	Strips-only or strips with diagonal or herringbone thinning between strips	
Thinning intensity (percent trees removed)	25 to 50	
Machine length (m)	2 to 5	
(ft)	6.5 to 16	
Machine width (m)	1.25 to 2.5	
(ft)	4 to 8	

Thinning between strips leaves an even more uniform tree distribution. We restricted the thinning patterns between the strips to a herringbone or a diagonal pattern but still many options are possible (fig. 4). The machine must be small enough to fit between the "leave" trees, and the length and turning ratio of the feller/buncher must allow the necessary maneuvering to thin the area between strips.

The thinning pattern must be chosen carefully in the densest stands, where removing double rows is necessary to allow the machine to work without damaging residual trees. Some patterns will allow too much clumping, large empty areas, and too many edge trees, resulting in undesirable branching and uneven stand growth (fig. 5). It is necessary to make the thinned area between strips as wide as possible to improve stand distribution over the double-row strip-only pattern.

Single- Versus Double-row Strip-only Thinning

For representative stands of each spacing category, thinnings of both single- and double-row strips were

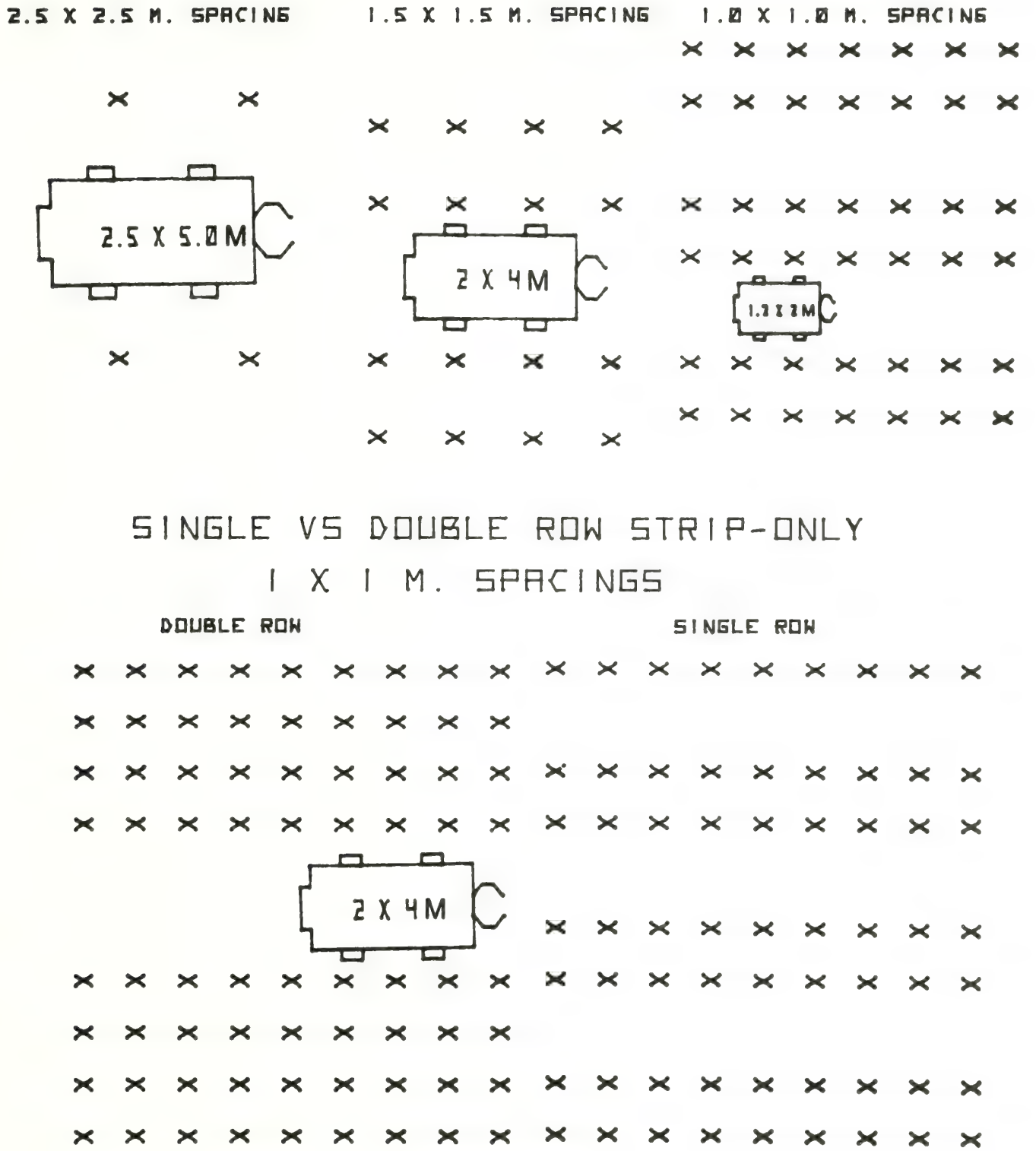
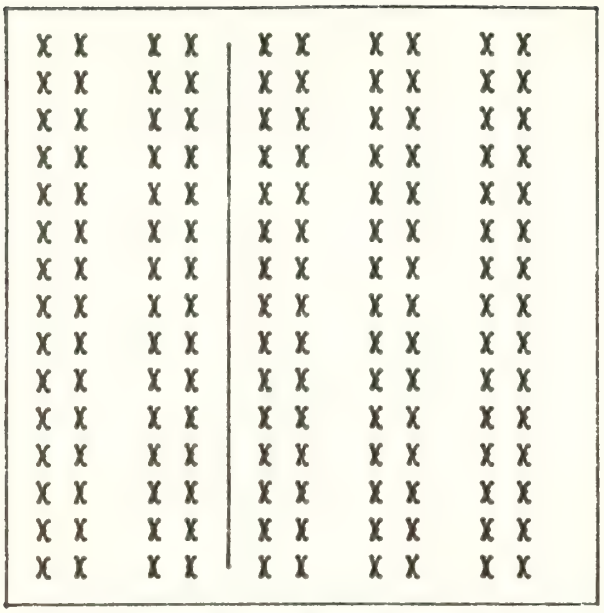
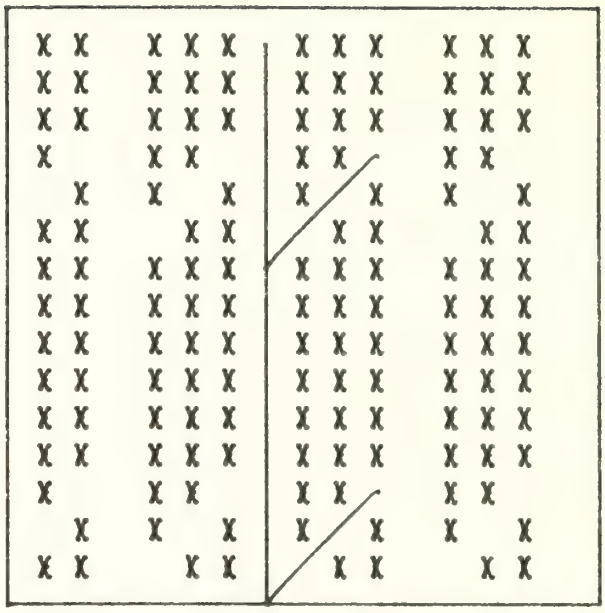


Figure 3.—*Limits on machine size due to tree spacing.*

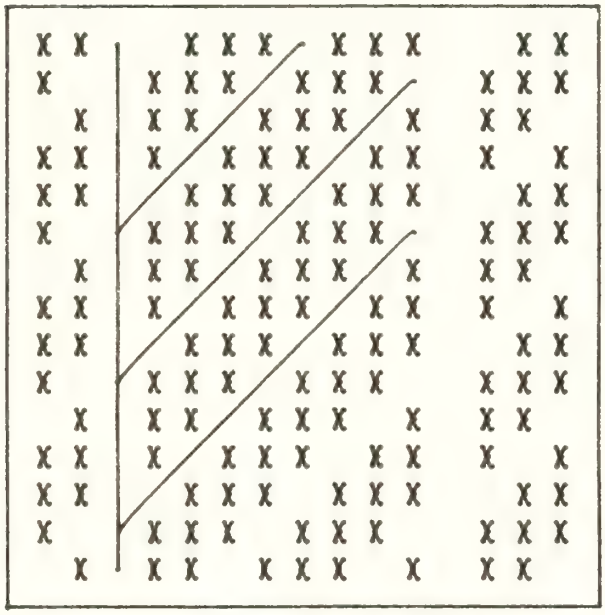
simulated with all machine variables set at their base values. Both the chassis-mounted and boom-mounted shear machine types behaved similarly, and production rates differed little (less than 10 percent) for double-row versus single-row strips (fig. 6). However, the number of trees collected per bunch for the skidder was almost twice as large for the double-row strip thinning. Because skidding or forwarding also affects total system cost, the larger bunch size from the double-row strip would more than offset the slight advantage of feller/buncher productivity of the single-row.



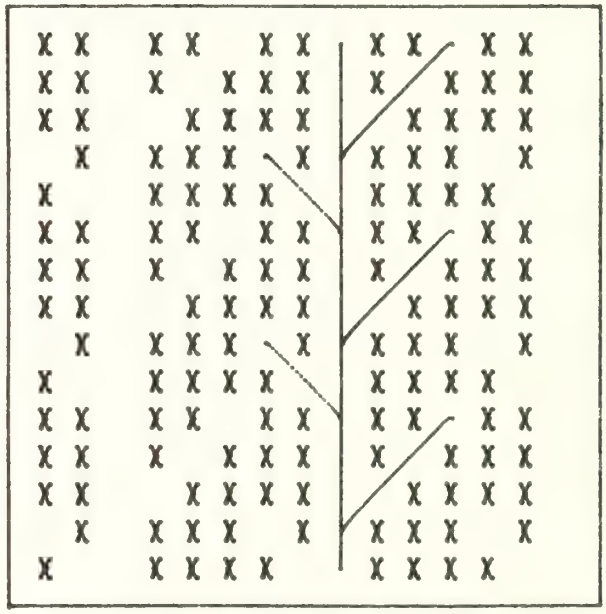
SINGLE ROW STRIP-ONLY



DIAGONAL THINNING OF THREE ROWS BETWEEN-STRIPS



DIAGONAL THINNING OF EIGHT ROWS BETWEEN-STRIPS



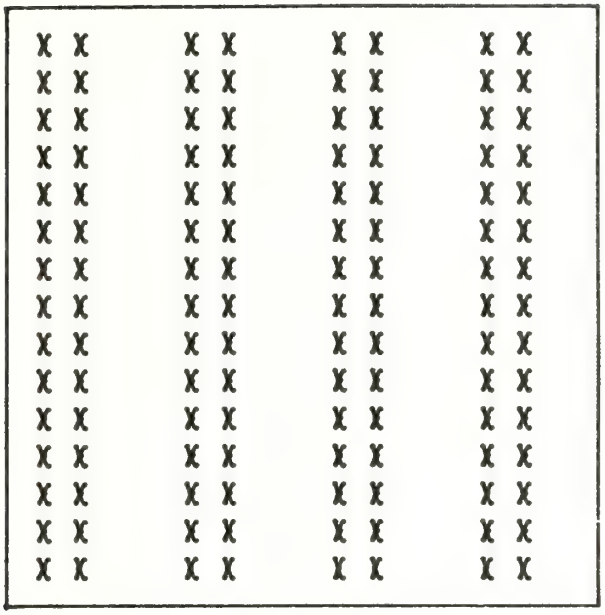
HERRINGBONE THINNING OF FIVE ROWS BETWEEN-STRIPS

Figure 4.—*Some possible thinning patterns to achieve a 33 percent tree removal.*

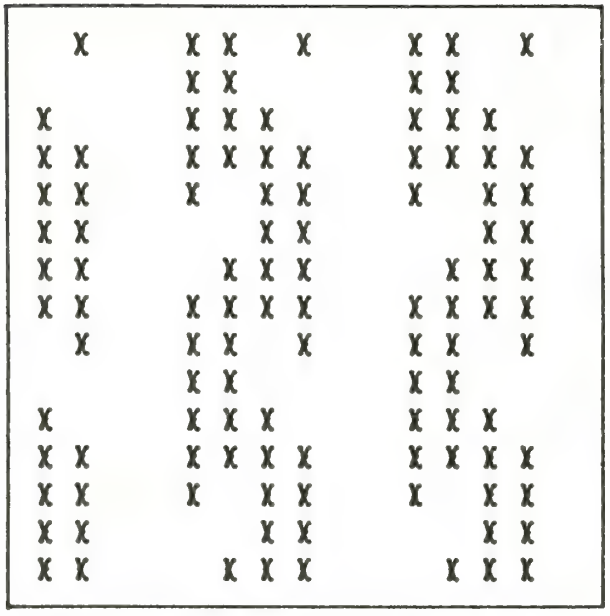
Herringbone and Diagonal Thinning Between Strips

Removing trees from the area between strips is more desirable silviculturally than strip-only thinning. To explore some facets of this type of thinning, we chose a thinning intensity of 33 percent because it offered a wide range of patterns. We simulated thinnings using both machines for each tree spacing, holding basal area constant at 35 m^2/ha (150 ft^2/acre). We picked an intermediate between-strip width of five rows to be thinned in diagonal and herringbone patterns. More trees are available from any location with thinning between the rows, so bunch sizes resemble those of the double-row strip-only.

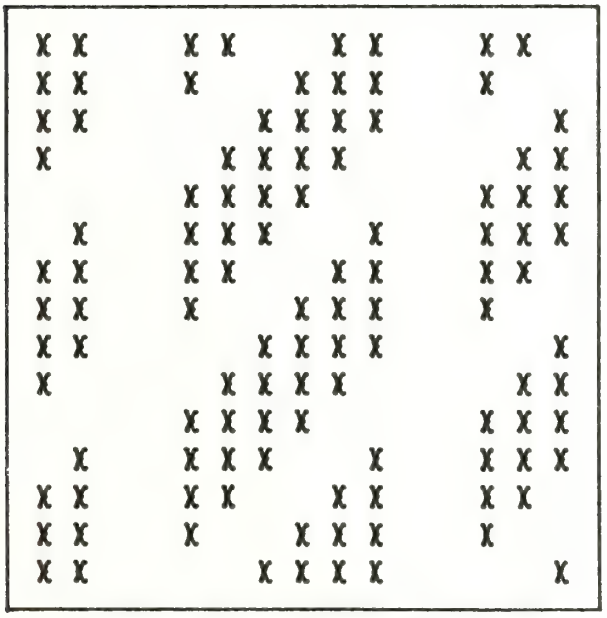
For both machines, productivity was reduced when the areas between strips were thinned (table 3). The chassis-mounted shear showed the greater decrease



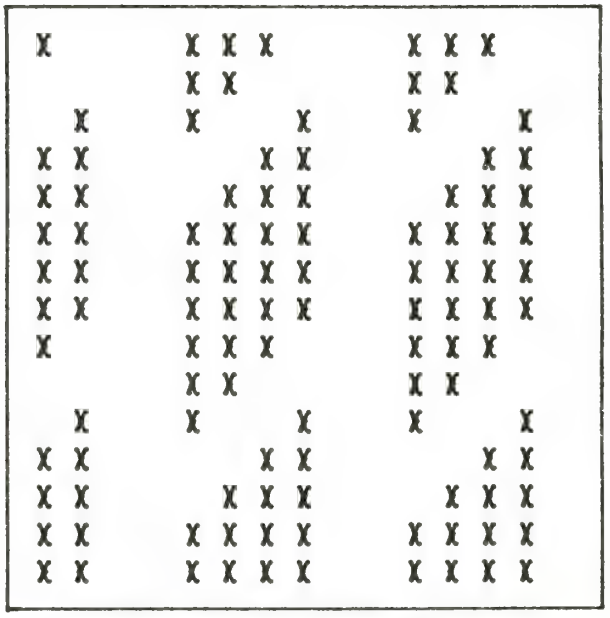
DOUBLE ROW STRIPS-ONLY



DOUBLE ROW HERRINGBONE THINNING
4 ROWS BETWEEN-STRIPS



DOUBLE ROW DIAGONAL THINNING
6 ROWS BETWEEN-STRIPS



DOUBLE ROW DIAGONAL THINNING
4 ROWS BETWEEN-STRIPS

Figure 5.—*Thinning patterns in closely spaced stands requiring removal of double rows 50 percent tree removal.*

(approximately 18 percent) due to the additional travel needed for each tree. The decrease in productivity from the strip-only is less consistent for the boom-mounted shear—it ranged from 5 to 23 percent. This is largely due to the higher production found in the 1.5- and 2.5-m spacings because of the particular boom reach chosen for the study.

For the feller/buncher with the chassis-mounted shear, it made no difference which pattern was chosen except for the 2.5-m-spaced trees. For that stand, thinning with a diagonal pattern was almost as efficient as strip thinning only. The tree diameter/accumulator size combination was such that the feller always had a full accumulator when it reached the end of the diagonal. For the 2-m-spaced plantation, however, almost 50 percent of the time the feller did not have a full accumulator load when it reached the end of the diagonal.

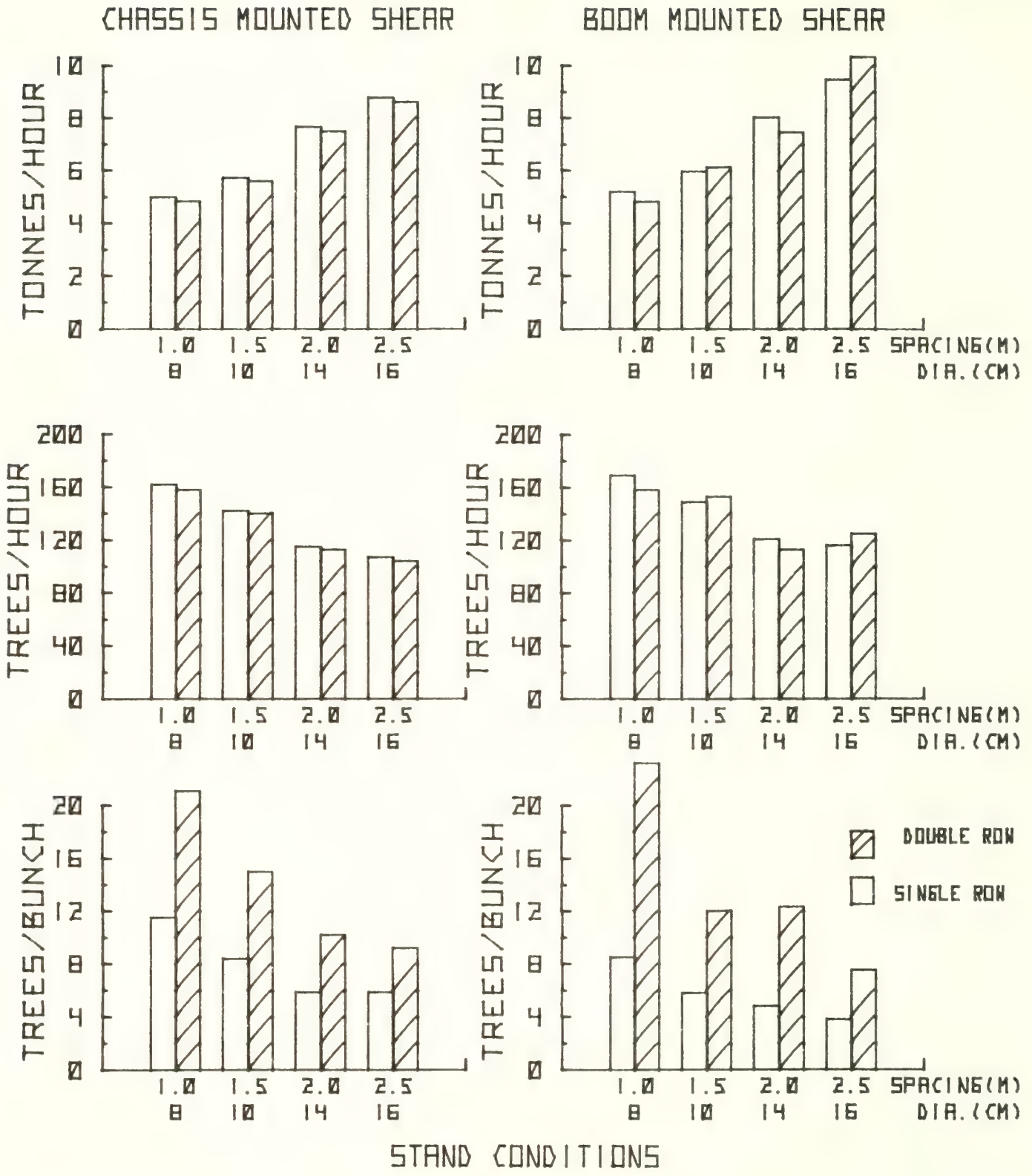


Figure 6.—*Effects on productivity—single row versus double row strips only.*

Table 3.—*Comparison of feller/buncher productivity—herringbone or diagonal thinning versus strips-only*

Productivity	Spacing (tree diameter)											
	1 × 1 m (6.7 cm)			1.5 × 1.5 m (10.0 cm)			2 × 2 m (13.3 cm)			2.5 × 2.5 m (16.7 cm)		
	Strip[1]	Diag[2]	Herr[3]	Strip	Diag	Herr	Strip	Diag	Herr	Strip	Diag	Herr
CHASSIS-MOUNTED SHEAR												
Trees/hour	170	143	137	140	116	118	120	99	100	104	98	83
Tonnes/hour	4.3	3.6	3.5	5.6	4.7	4.7	7.4	6.1	6.2	9.2	8.7	7.4
Decrease in tonnes/hour (percent of strip-only)		16	1 9		16	16		18	16		5	20
Trees/bunch	21	23	23	15	14	13	11	11	11	9	9	9
Distance traveled/ tree (m)	8.0	11.6	12.1	11.5	16.2	15.4	14.7	20.9	20.3	9.1	21.3	26.9
BOOM-MOUNTED SHEAR												
Trees/hour	167	156	154	154	122	129	122	110	115	125	96[4]	103
Tonnes/hour	4.2	4.0	3.9	6.1	4.9	5.2	7.6	6.8	7.1	11.1	8.5	9.2
Decrease in tonnes/hour (percent of strip-only)		5	7		20	15		11	7		23	17
Trees/bunch	25	25	24	12	18	16	14	9	12	8	8	10

[1]Strip-only—double-row strip-only, 33 percent removal.
[2]Diagonal—single-row strip with five thinned rows between, 33 percent removal.
[3]Herringbone—single-row strip with five thinned rows between, 33 percent removal.
[4]Ten percent of trees missed because they were beyond reach of the boom.

The choice between a herringbone and diagonal thinning pattern for the boom-mounted shear machine had a significant affect on production once—in the 2.5 m spacing. Because of the length of the diagonal, 10 percent of the trees marked for thinning were missed because they were beyond the reach of the boom. The particular spacing at which this becomes a problem depends upon boom length and number of rows in the selection area. However, this generally can be avoided by using a herringbone pattern.

Effect of Thinning Intensity

When thinning in strips only, the proportion of trees removed affects only the width of the between-strip area. For these closely spaced trees, this difference in width is not sufficient to affect productivity in terms of tonnes/hour or trees/hour. But, of course, it does affect the hectares per hour because the number of trees removed per hectare changes with thinning intensity (table 4).

Many different between-strip widths can be used to achieve the same overall thinning level. For example, some of the options for removing 25 percent of the trees in a stand using single-row strips with between-strip thinning are:

Between-strip width (No. rows)	Fraction of trees to be removed from each row
5	1/10
7	1/7
9	1/6
15	1/5

Each option results in a different diagonal length and a different number of trees available from a given machine location, affecting travel and boom reach time and the number of accumulator loads. In addition, trees will be out of reach for the boom-mounted shear for some options and spacings.

Table 4.—*Productivity of the chassis-mounted shear for different thinning intensities*

Thinning intensity[1] (percent)	Trees/ hour	Tonnes/ hour	Hectares/ hour
25	139	5.6	0.13
33	140	5.6	0.10
50	140	5.6	0.06

[1]*Stand spacing 1.5 m; 10 cm average tree diameter.*

The difference in productivity caused by the choice of between-strip width is greater than the differences caused by percent tree removal or the choice of the herringbone or diagonal pattern (fig. 7). The optimal

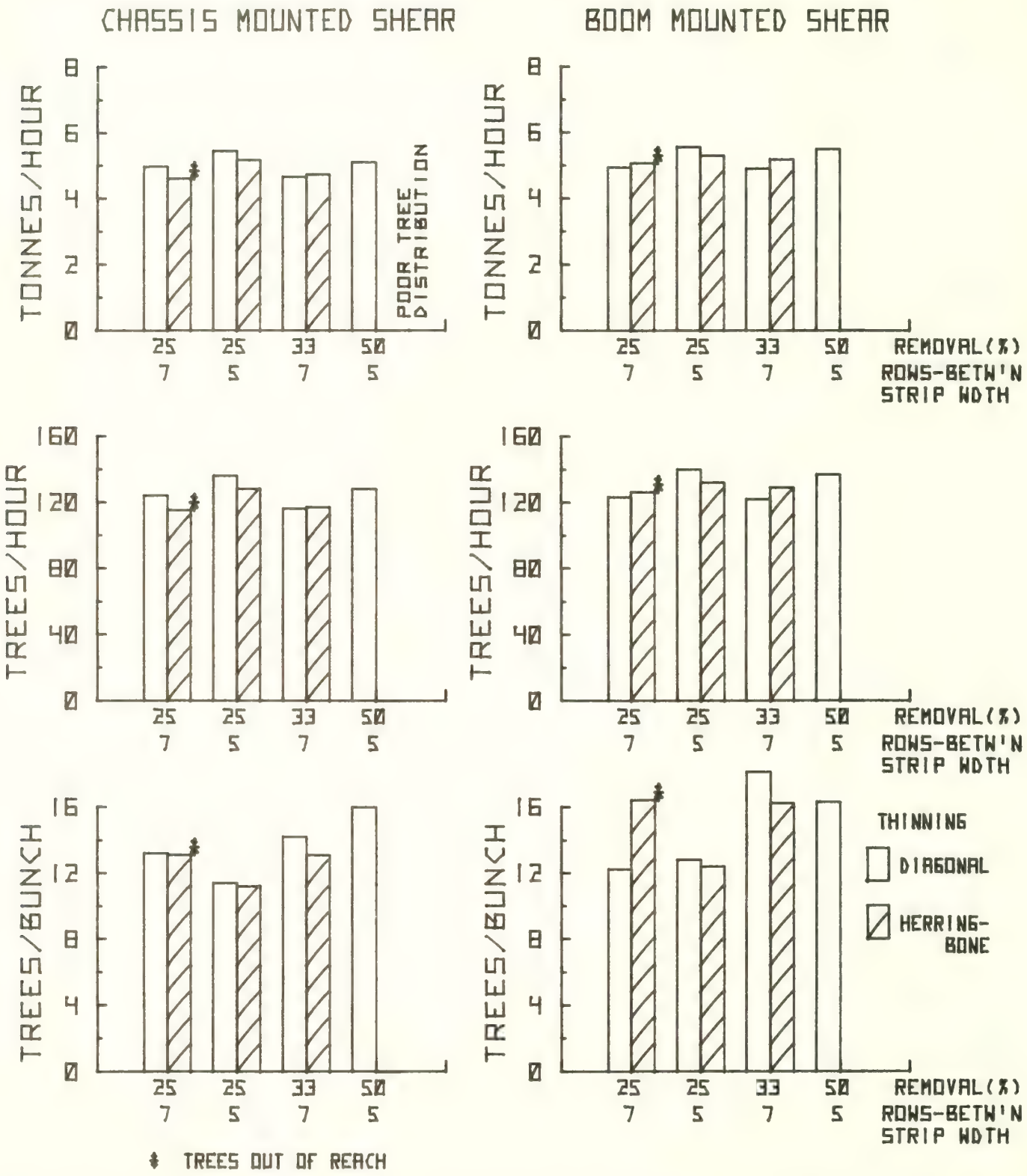


Figure 7.—*Effects on productivity—percent tree removal, between strip width, and thinning pattern.*

between-strip width for a given pattern and tree removal rate will depend on tree spacing, tree diameter, accumulator head capacity, and boom reach (for the boom-mounted shear). This interaction of factors makes it difficult to determine the optimum width, and it deserves a separate analysis.

Herringbone and Diagonal Thinnings in 1- by 1-m Spacings

To permit machine maneuverability and to avoid tree damage in dense stands—i.e., 1- by 1-m spacings—it may be necessary to remove a double row of trees when thinning the between-strip area. To determine what effect this would have on productivity, we simulated a 50-percent removal rate with a diagonal pattern of both single and double rows (table 5).

Productivity increased while bunch size remained similar in contrast to the strip-only thinning where productivity was similar, but the bunch size doubled when double rows were cut. Overall efficiency improved because of the greater number of trees available for each pass the machine or boom had to make into the between-strip area.

MACHINE CHARACTERISTICS

An understanding of how productivity is affected by each of the machine characteristics could lead to development of the most efficient machine for these thinnings (table 6).

An accumulator head to collect multiple stems increases productivity. The number of stems the accumulator can hold depends on the size of the individual trees. To specify the size of the accumulator, we used a total sum of tree diameters. We studied a range of machines from these with no accumulating ability to machines with an accumulating capacity of 55 cm—that is, nine 6-cm trees or four 16-cm trees. This would be an accumulating head approximately 40 cm (16 in.) in diameter capable of handling 250 Kg or 500 to 600 lbs. We felt that a larger accumulator would not be mechanically feasible on these small machines.

Table 5.—*Effect of removing double rows in the between-strip area*

	Chassis-mounted		Boom-mounted	
	Single row	Double row	Single row	Double row
Trees/hour	141	148	151	176
Tonnes/hour	3.6	3.8	3.8	4.5
Trees/bunch	22	28	27	24

Table 6.—*Feller/buncher machine characteristics*

Variable	Range	Base value
Shear accumulator		
Capacity—total diameter (cm)	0 to 55	30
(in.)	0 to 22	12
Average travel speeds		
Chassis-mounted shear (k/hr)	2 to 8	4
(mph)	1.2 to 4.8	2.4
Boom-mounted shear (k/hr)	1 to 4	2
(mph)	.6 to 2.4	1.2
Average shear time (min/stem)	.1 to .4	.2
Average drop time (min/load)	.1 to .4	.2
Boom reach speed—boom-mounted only		
Unloaded (m/sec)	.5 to 2	1
(ft/sec)	1.7 to 6.7	3.3
Loaded—10 percent longer for each tree in accumulator head		
Boom reach		
Minimum (m)	2 to 3	2
(ft)	6.5 to 10	
Maximum (m)	5 to 15	10
(ft)	15 to 50	

Travel speeds in the woods have been shown to be normally distributed, with a standard deviation from 25 to 30 percent of the average value (Blinn 1983). The simulation model samples a normal distribution to obtain each travel speed. The average travel speeds were chosen to cover the range of values observed in the field. In general, machines carrying a boom are slower than those with a fixed shear, so we chose a greater base speed for the fixed shear.

Neither shear times nor drop times are normally distributed. Approximately 3,500 field observations were used to develop distributions for shear and drop times (fig. 8). These distributions were then normalized to the mean so they could be used with the different mean values and still maintain their properties. The base values were taken as being equal to the field observation means, while the "fast" and "slow" times were one-half and twice the base values, respectively. The simulation program sampled these distributions for each shear and drop time.

One meter per second was determined to be a reasonable boom travel speed. Again, one-half and twice that rate were used for the "slow" and "fast" limits to determine effect of boom speed on production. Boom travel time was increased 10 percent for each tree in the accumulator head to compensate for maneuvering and the additional weight. Boom reach was limited to the range of values for currently available machines.

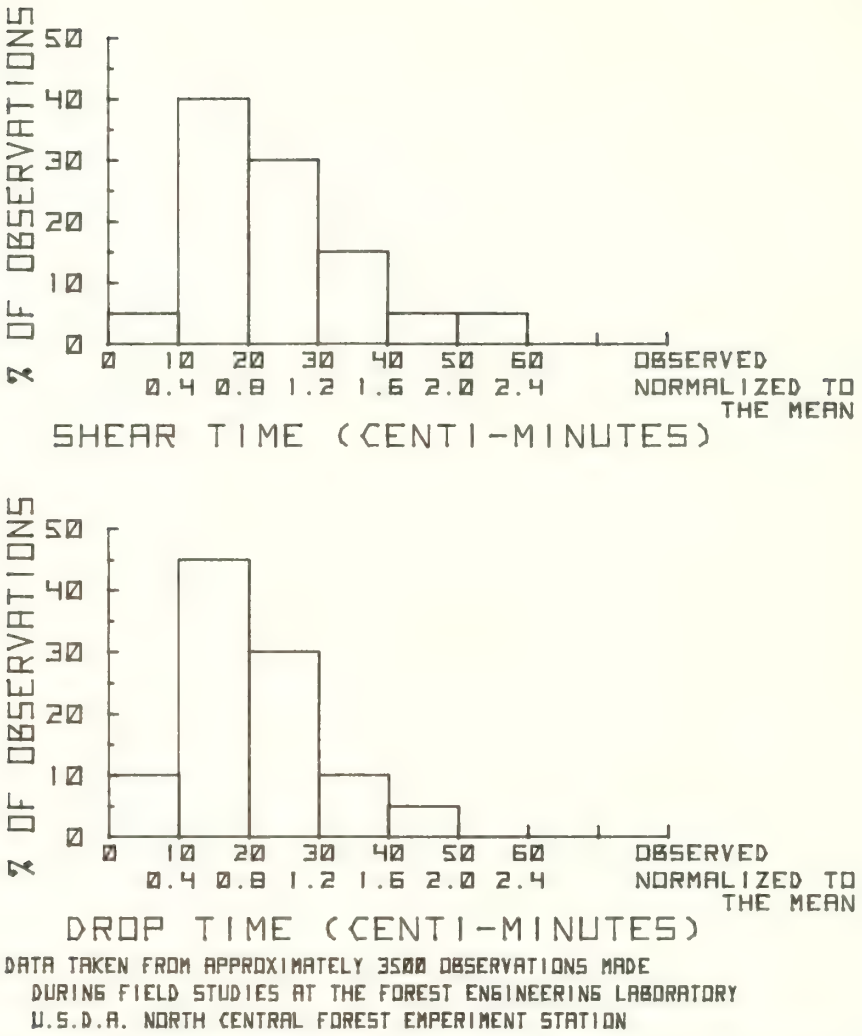


Figure 8.—*Distributions of shear and drop times used in simulation model.*

Sensitivity of Productivity to Machine Variables

To determine sensitivity of production to each of the machine variables, runs were made for both machine types changing one variable at a time. Each variable was tested at a "slow" and "fast" rate, and the results were compared to the standard runs; i.e., all values set to base values (table 7). Runs were also made with all machine variables set "slow" and then all set "fast" to obtain lower and upper bounds on production rates. These runs were all made at the 1.5-m spacing and an average tree diameter of 10 cm giving a basal area of 35 m^2/ha (150 ft^2/acre). Shear rate greatly affected productivity for both machine types. Productivity increased at least 30 percent when average shear time is reduced from 0.2 to 0.1 minute per tree. Travel speed also significantly affected productivity for the fixed-head shear; however, it made little difference for the boom-mounted machine. Because machine travel is replaced with boom motion for that machine, the boom reach speed becomes the significant factor.

The most important machine characteristic is the existence of an accumulating head. We assumed an accumulator for the base value. Increasing the size of the accumulator; i.e., the "high" value, increases production by 15 to 30 percent. However, if no accumulator is used, production drops 50 percent! The number of trees the accumulator head can hold depends upon tree size; the small head can hold four or five small trees but only one or two large ones. Additional runs for various tree spacings and average tree diameters were made to further investigate the effect of the use and size of an accumulating head. Trees per hour and tonnes per hour increase dramatically with the use of an accumulator (fig. 9). For small trees, the production rate with a large accumulating head is three times that of no acculmulator.

Table 7.—*Sensitivity of feller/buncher productivity (tonnes/hour) to changes in machine variables*

Production	Fixed-head shear	Boom-mounted shear
Minimum—all machine values set low	1.34 tonnes/hr (-77%)	1.67 tonnes/hr (-73%)
Average—all machine values set base	5.59 tonnes/hr	6.12 tonnes/hr
Maximum—all machine variables set high	14.97 tonnes/hr (+168%)	15.55 tonnes/hr (+154%)

	Variable		Fixed-head shear		Boom-mounted shear	
			Change in production (percent)			
Machine	Low rate	High rate	Low	High	Low	High
Travel speed						
Fixed-head	2 k/hr	8 k/hr	-31	29		
Boom-mounted	1 k/hr	4 k/hr			-5	5
Shear rate	0.4 min/tree	0.1 min/tree	-30	31	-32	34
Drop rate	0.4 min/tree	0.1 min/tree	-12	9	-14	11
Accumulator head capacity (total diameter)	No accumulator	55 cm (large)	-50	29	-43	16
Boom reach speed	0.5 m/sec	2 m/sec			-33	23

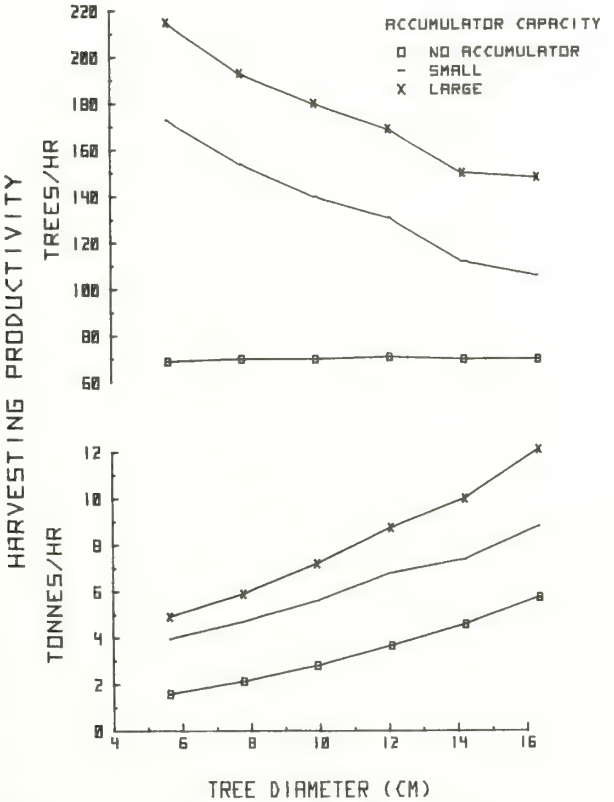


Figure 9.—*Effects of accumulator head on productivity.*

For large trees, the production rate is twice that of no accumulator. Also when using an accumulator head skid bunch size increases which is an additional advantage when considering the entire system.

Additional thinnings were tested with a herringbone pattern between strips for machines with various accumulating capacities. The percent change in production due to eliminating the accumulator or increasing its capacity is identical to those outlined in the preceding paragraph.

Maximum and Minimum Boom Extension

To determine the effect of the boom reach limits, runs were made for each spacing at a basal area of 35 m^2/ha. In these dense stands, the shorter the boom reach, the higher the productivity (fig. 10). We feel this is due to the close spacings and the nature of the strip thinnings. Although a machine with a shorter boom reach spends more time traveling, the extension time for the boom is shorter and overall productivity is greater. This effect was less pronounced as the boom travel speed increased. Production increase was at the expense of leaving smaller bunches for the skidder or forwarder; those from a machine with a 5-m boom were one-half the size of those made with a 10- or 15-m boom.

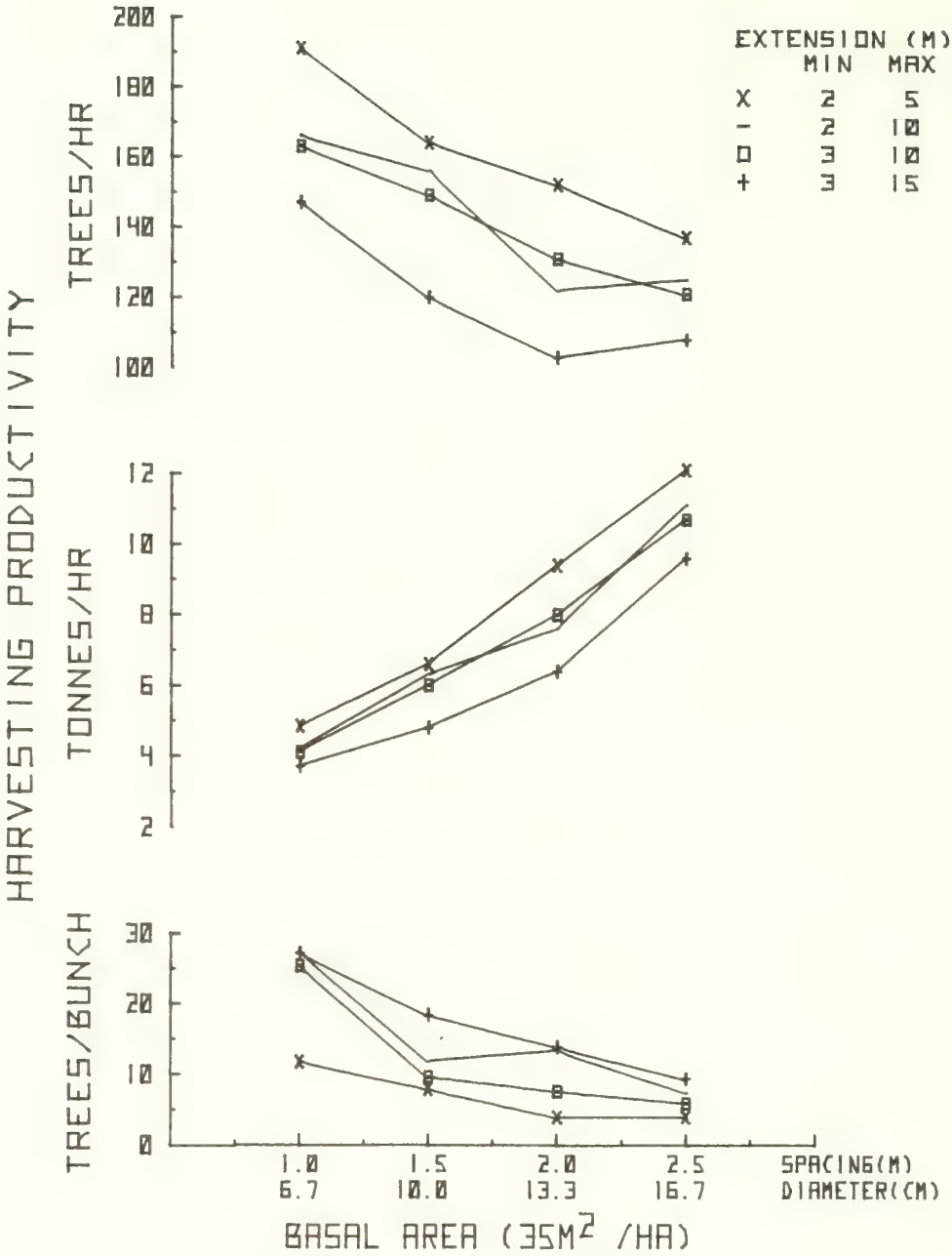


Figure 10.—*Effects of boom extension on harvesting productivity.*

Changing the minimum boom reach; i.e., how close the shear could be to the machine, produced less well-defined results. Bunch sizes for the 3-m minimum reach decreased slightly, but the productivity was affected more by the boom/spacing interaction than the minimum distance. Boom rech is a more critical factor when the thinning pattern involves more than just removing strips. It is necessary for the boom to be able to reach all the trees to be removed in the thinned areas, particularly in the diagonal pattern.

CONCLUSIONS

The purpose of this analysis was to determine the effect of various factors on the performance of feller/bunchers in thinning plantations. The validity of the results derived from this analysis is subject to the assumptions made in developing and implementing the simulation models. Our approach addressed the sensitivity of production to each variable independently. It was impossible to consider all the possible

characteristics and their interactions, yet the values considered for each variable were within the range of current conditions and technology. Therefore, the results of this study should be useful in determining the elements of machine design and operation that warrant the most attention. In particular, the use of an accumulator head and/or an increase in cutting speed can significantly improve productivity. This indicates that new concepts providing for simultaneous cutting and/or collecting of multiple stems could greatly enhance the mechanized harvesting of these plantations.

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Computer simulation was used to identify possible areas for improving the design and operation of feller/bunchers for thinning closely spaced plantations. Some of the variables considered were average stand diameter, tree spacing, thinning pattern, operational machine speeds, and shear head accumulating capacity.

KEY WORDS: Simulation, machine characteristics, stand characteristics, computer, felling.

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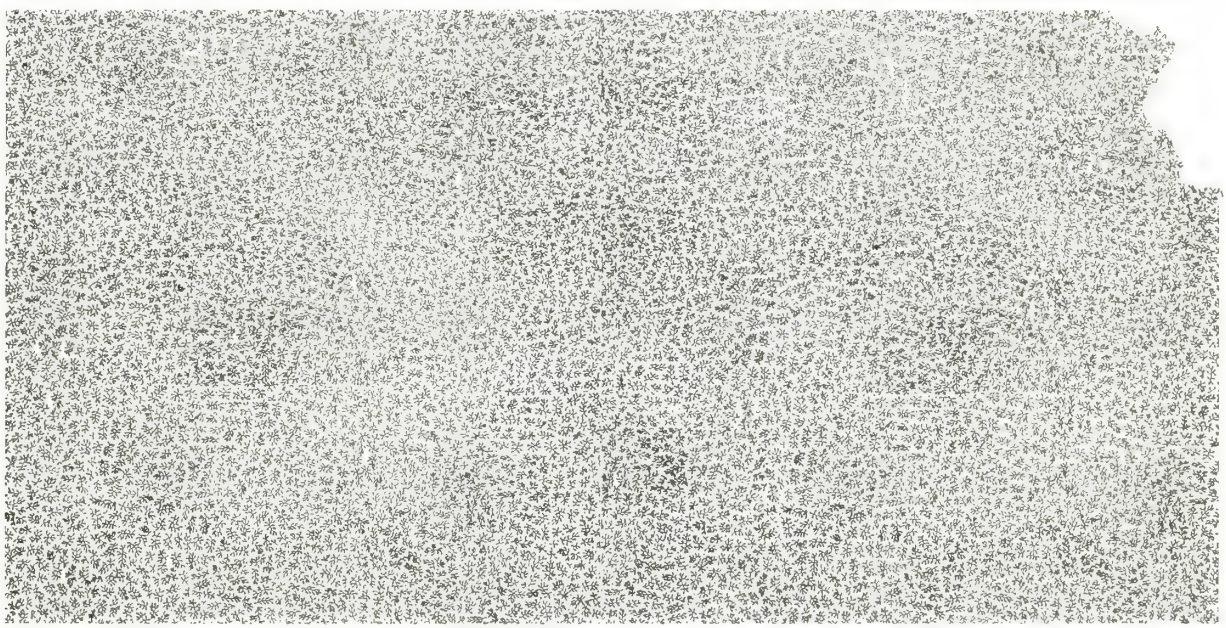
Research Paper **NC-255**

Forest Treatment Opportunities for Kansas 1982-1991

W. Brad Smith and W. J. Moyer



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CONTENTS

	Page
Assumptions	2
Method	2
Findings	3
Discussion	4
Appendix	5
Principal Tree Species Groups in Kansas	5
Definition of Terms	6
Metric Equivalents of Units Used in this Report	8
Tables	8

FOREST TREATMENT OPPORTUNITIES FOR KANSAS 1982-1991

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Forest Inventory and Analysis (or Forest Survey) is a continuing endeavor as mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974. Its objective is to periodically inventory the Nation's forest land to determine its extent, condition, and volume of timber, growth, and depletions. In 1981, the Forest Inventory and Analysis Project at the North Central Forest Experiment Station conducted the third forest survey of Kansas in cooperation with State and Extension Forestry, Kansas State University.

Kansas is not noted for its forests; however, the State has 1.4 million acres of wooded land that is vital to the quality of life in the area. Kansas' forests, primarily hardwood, are composed of two major forest type groups: oak-hickory and elm-ash-cottonwood. Oak-hickory is found mostly on the eastern uplands, while elm-ash-cottonwood is abundant in the eastern lowlands and along the stream bottoms into the western reaches of the State (fig. 1).

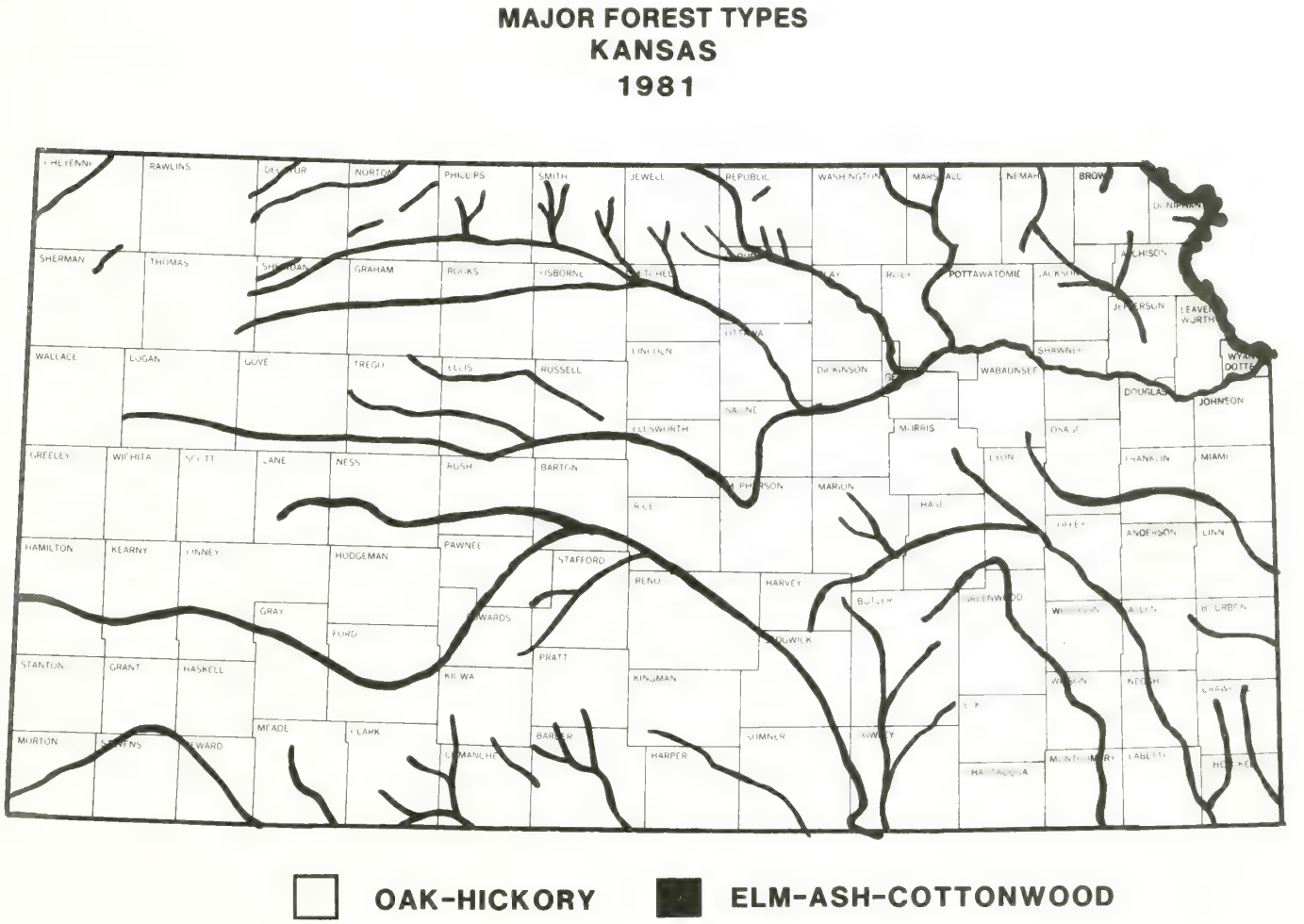

Figure 1.—*Kansas forest type groups map.*

These forests provide timber products as well as shelter and protection for homes, farmsteads, fields, and wildlife. As shown in the following tabulation, in 1981 approximately 1.2 million acres of this wooded land is commercial forest land deemed capable of producing commercial crops of timber and is not withdrawn from utilization by statute or administrative regulation.

Land Class	Area (Acres)
Forest land	
Commercial	1,207,900
Noncommercial	150,800
Total	1,358,700
Nonforest land	50,979,300
Total all land	52,338,000

The potential for managing commercial forest land in Kansas is the subject of this report. Treatment opportunities during the decade 1982-1991 were identified for projected forest conditions in Kansas. The treatments evaluated were: (1) harvest, (2) thinning (commercial and precommercial), and (3) stand conversion or restocking. We compared projected stand conditions to treatment criteria and determined the area qualifying for each treatment during the decade. Timber volumes occurring in stands selected for treatment were tabulated; they represent what could be removed if treatments were carried out.

Treatment criteria for Kansas were adopted from criteria identified in conjunction with the State and Extension Forestry Office and management practices identified in other Plains States. They reflect management practices feasible for current forest conditions on commercial forest land in the State (table 1).

There is no single or correct evaluation of treatment opportunities for Kansas. Rather, opportunities differ according to the treatment criteria specified. The findings presented here are the result of just one of many possible sets of treatment options.

ASSUMPTIONS

In order to conduct the analysis, we made three basic assumptions: (1) the area of commercial forest land (1.2 million acres) will remain stable for the decade 1982-1991, (2) all commercial forest land is available for treatment, and (3) a ready market exists for all species and products. We did not consider possible economic, social, or political constraints on treatment opportunities.

METHOD

Treatment opportunities are projected for a decade because this is viewed as a reasonable planning period, and because ideally, forest inventories are conducted every 10 years. In practice, treatments would occur throughout the decade. An estimate of the average annual volumes removed during the treatment period should reflect the growth that would occur on plots between 1981 (when the data were collected) and the time of treatment. Therefore, we projected each plot 5 years as an estimate of average

Table 1.—*Harvest and timber stand improvement criteria used in assessing treatment opportunities, Kansas, 1982-1991*

Forest type	Site index range	Rotation age for harvest	Thinning[1]	
			Pre-thinning basal area	Post-thinning basal area
	Feet	*Years*	*----Square feet----*	
Eastern redcedar-hardwood	All sites	60	—	—
Post-blackjack oak	0-55	100	90	65[2]
	56+	80	90	65[3]
Oak-hickory	0-55	100	90	65[2]
	56+	80	90	65[3]
Upland elm-ash-locust	All sites	90	90	65
Upland plains hardwoods	0-55	100	90	65[2]
	56+	80	90	65[3]
Cottonwood	All sites	40	—	—
Willow	All sites	40	—	—
Lowland plains hardwoods	All sites	70	90	70
Elm-ash-cottonwood	All sites	70	90	70

[1]Stands must be more than 10 years from harvest age to be considered for thinning.
[2]Stands must be less than 41-years-old to be considered for thinning.
[3]Stands must be less than 51-years-old to be considered for thinning.

growth for the decade before we evaluated treatments. To accomplish this, plot data from the 1981 Kansas Forest Inventory were used as input to the Stand and Tree Evaluation and Modeling System (STEMS).[1] The System "grew" each plot for 5 years, calculating areas and volumes represented by the plots. After the projection, we used the following process to identify treatment opportunities (fig. 2):

(1) Identify areas for stand conversion or restocking

The basal area for each plot was compared to the stand age to see if the plot would achieve full stocking. A plot was selected for stand conversion or restocking if plot basal area was less than 19 +(0.38 ×stand age).

(2) Identify areas for harvest

Harvest acreage was calculated for each forest type for the decade 1982-1991 using criteria outlined in table 1. All plots at rotation age or above were selected for harvest. Harvest volume is the projected volume found on harvest plots.

(3) Identify areas for thinning

Thinning acreage was calculated for each forest type for the decade 1982-1991 using criteria outlined in table 1. Stands selected for thinning must be at least 10 years less than rotation age. In the oak forest type, thinning on better sites would occur only in stands less than 51-years-old. Thinning on poor sites would occur only in stands less than 41-years-old.

On plots selected for thinning, STEMS assigned the highest thinning priority to cull trees, then growing-stock trees of undesirable species (elm, boxelder, and noncommercial species), and finally growing-stock crop trees. Large diameter growing-stock crop trees were favored for retention during thinning operations. Trees were "thinned" from the plot until the recommended post-thinning basal area was reached. Thinning volume is the projected volume of trees removed during thinning.

FINDINGS

Harvest Treatment Opportunities

Area

According to the treatment criteria used in this analysis, 293,244 acres of commercial forest land could be harvested by 1991 (Appendix table 5). Many of the stands in Kansas are mature and should be harvested. Seventy-eight percent of the total cottonwood acreage qualified for harvest, as did 31 percent

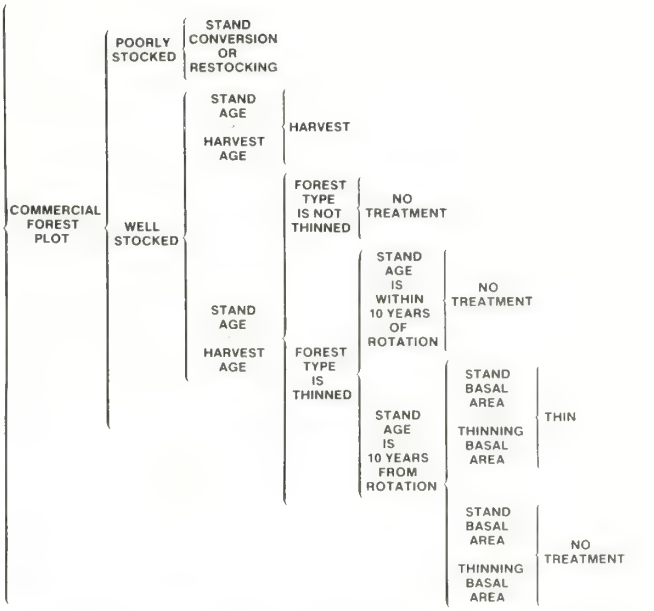

Figure 2.—*Logic used to assign treatments to each forest inventory plot.*

of the lowland plains hardwoods acreage, and 25 percent of the elm-ash-cottonwood acreage. In the cottonwood forest type many of the stands are overmature—more than half of the stands are at least 20 years past the identified rotation age. Although some of the cottonwood stands identified for harvesting are on sites with a low site index, nearly three-fourths of the sites have a site index over 60.

Volume

Timber volume on commercial forest land selected for harvest totals 43.7 million cubic feet annually during the decade, 40.4 million cubic feet in growing-stock trees. An average of 1,379 cubic feet of growing-stock including 4,542 board feet of sawtimber would be removed for every acre of commercial forest land harvested. Growing-stock and sawtimber removals are highest in the cottonwood forest type at 2,094 cubic feet per acre and 7,072 board feet per acre, respectively.

Forest type	Average harvest volume per acre	
	(Cubic feet)	(Board feet)[2]
Eastern redcedar-hardwood	936	2,238
Post-blackjack oak	812	2,846
Oak-hickory	1,093	3,803
Upland elm-ash-locust	927	2,073
Upland plains hardwoods	1,010	2,388
Cottonwood	2,094	7,072
Willow	369	876
Lowland plains hardwoods	1,325	4,514
Elm-ash-cottonwood	1,289	3,922
All types	1,379	4,543

[1] *U.S. Department of Agriculture, Forest Service. A description of STEMS: The stand and tree evaluation and modeling system. Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 18 p.*

[2] *International ¼-inch rule.*

Thinning Treatment Opportunities

Area

During the decade, 105,928 acres of commercial forest land qualified for thinning. The oak-hickory, lowland plains hardwoods, and elm-ash-cottonwood forest types accounted for 83 percent of all stands in need of thinning.

All the thinned stands were between 30- and 70-years-old. The average site index of stands selected for thinning was 70. Although most of the thinned area is in stands less than 20 acres in size, 3,713 acres annually are in stands at least 20 acres in size (table 2).

Volume

Volumes from thinnings total 7.2 million cubic feet annually for the decade, 5.9 million cubic feet in growing-stock trees. The average growing stock removed during thinnings is 554 cubic feet per acre thinned. Oak, elm, ash, and hickory poletimber trees account for 41 percent of the growing-stock volume thinned.

Stand Conversion or Restocking Treatment Opportunities

Area

Because of inadequate stocking, 147,872 acres of commercial forest land in Kansas will be targeted for stand conversion or restocking during the decade. These stands include 54,957 acres of upland forests and 47,515 acres of lowland forests. Additionally, 45,400 acres of nonstocked forest land would be restocked. The average site index of stands selected for stand conversion or restocking is 58. Forty-six percent of these areas are stands less than 10 acres in size.

Table 2.—*Annual area of commercial forest land qualifying for treatment by stand-size class and treatment class, Kansas, 1982-1991*

(in acres)

	Treatment class		
Stand size	Harvest	Thinning	Stand conversion or restocking
1-4 acres	7,165	1,798	3,384
5-9 acres	6,996	3,061	4,944
10-19 acres	7,620	2,020	2,515
20-39 acres	3,815	1,578	1,534
40-79 acres	2,121	580	887
80-159 acres	1,125	1,209	753
160-319 acres	367	347	642
320-639 acres	115	—	128
All classes	29,324	10,593	14,787

Volume

If stands to be converted or restocked were clearcut before treatment, 4.0 million cubic feet of timber could be recovered annually—3.4 million cubic feet in growing-stock trees. This averages 232 cubic feet of growing stock removed per acre undergoing stand conversion or restocking. Most of the growing-stock volume removed is in sawtimber-size trees, with oak and cottonwood sawtimber accounting for 41 percent of the volume.

DISCUSSION

According to the criteria used in this analysis, 547,044 acres of commercial forest land would benefit from some treatment during the decade 1982-1991. The most common treatments needed are restocking, stand conversion, and harvest. Restocking and stand conversion are needed on 147,872 acres during the decade, while harvest is needed on 293,244 acres.

The harvest opportunities identified here will not result in a sustained yield or even flow of timber volume from Kansas' forest land. The annual harvest area and volume under even-flow management would be less than that shown here.

In order to put Kansas treatment opportunities into perspective, it is useful to compare potential annual harvest of various species during the next decade with harvest figures from recent surveys. Generally, the supply of harvestable timber from commercial forest land appears to be adequate during the next decade to meet the current demand for product raw materials (Appendix, table 3). Notable exceptions are black walnut sawtimber and eastern redcedar growing stock and sawtimber. If the 1980 demand level persists, sources other than harvest of commercial forest land will have to be tapped to provide the supply. Thinning on commercial forest land will provide some relief, but timber from silvicultural activities on other land classes such as wooded pasture and wooded strips will be more likely sources of the total additional material required.

The demand for oak, ash, and hackberry has increased sharply since the mid-1960's. Demand for fuelwood has accounted for a good portion of this increase. If this trend continues, pressure almost certainly will be increased on the supplies of these species for saw log products.

Fuelwood was the most prominent forest product in Kansas in 1980, comprising 63 percent of the growing stock and 48 percent of the sawtimber harvested in the State (Appendix, table 4). The potential for commercial management opportunities other than fuelwood seem greatest in hardwood saw logs and veneer. Increased walnut management is one attractive alternative given the species' high value, high demand, and tight supply situation.

For many reasons, the treatments identified here may not be carried out. Wood production may not be a priority for some land owners. These owners may consider timber management incompatible with their ownership objectives. Social or political considerations may limit timber management. Traditional markets may not exist for some of the products removed during treatment. Distance to markets may make some treatments uneconomical. However, with interest running high for using wood biomass and with new technology developing, new markets may be opening for many products. Stand size is another concern in assessing treatment opportunities which relates to the extent of the forest in the same general management condition. Forty-seven percent of all areas targeted for treatment during the next decade are less than 10 acres in size.

Therefore, the acreages targeted for treatment in this report are the biological maximum available, given the treatment criteria and current Kansas forest conditions. Forest managers and planners can use their knowledge of the local resource to temper the findings to fit conditions in their areas. Additionally, in many cases landowner interest in multiple benefits such as soil and watershed protection and wildlife enhancement may provide the added incentive to apply treatment to woodlands where wood production alone is not sufficient incentive.

Although this report has been devoted solely to commercial forest land, other excellent opportunities exist for managing timber on land not classified as commercial such as wooded pasture, wooded strips, and windbreaks—together they cover some 546,000 acres in the State. Landowners who would like guidance in obtaining trees, improving their stands, or harvesting timber are advised to contact State and Extension Forestry, Kansas State University, Manhattan, Kansas 66502, or their County Extension Office. Detailed statistical and analytical reports covering other aspects of the recent Statewide forest inventory are also available by contacting State and Extension Forestry, 2610 Claflin Road, Manhattan, Kansas 66502, or the Forest Inventory and Analysis Unit, USDA Forest Service, North Central Forest Experiment Station, 1992 Folwell Avenue, St. Paul, MN 55108.

APPENDIX

PRINCIPAL TREE SPECIES GROUPS IN KANSAS[3]

Softwoods
- Eastern redcedar ..... *Juniperus virginiana*

Hardwoods
- White oak
  - Bur oak ..... *Quercus macrocarpa*
  - White oak ..... *Quercus alba*
  - Chinkapin oak ..... *Quercus muehlenbergii*
  - Post oak ..... *Quercus stellata*
- Red oak
  - Northern red oak ..... *Quercus rubra*
  - Shumard oak ..... *Quercus shumardii*
  - Black oak ..... *Quercus velutina*
  - Blackjack oak ..... *Quercus marilandica*
  - Pin oak ..... *Quercus palustris*
  - Shingle oak ..... *Quercus imbricaria*
- Hickory
  - Pecan ..... *Carya illinoensis*
  - Shellbark hickory ..... *Carya laciniosa*
  - Mockernut hickory ..... *Carya tomentosa*
  - Shagbark hickory ..... *Carya ovata*
  - Bitternut hickory ..... *Carya cordiformis*
  - Black hickory ..... *Carya texana*
- Basswood
  - American basswood ..... *Tilia americana*
- Hard maple
  - Sugar maple ..... *Acer saccharum*
- Soft maple
  - Silver maple ..... *Acer saccharinum*
- Elm
  - American elm ..... *Ulmus americana*
  - Siberian elm ..... *Ulmus pumila*
  - Slippery elm ..... *Ulmus rubra*
- Ash
  - Green ash ..... *Fraxinus pennsylvanica*
  - White ash ..... *Fraxinus americana*
- Sycamore ..... *Platanus occidentalis*
- Cottonwood
  - Eastern cottonwood ..... *Populus deltoides*
- Willow
  - Black willow ..... *Salix nigra*
- Hackberry ..... *Celtis occidentalis*
- Black cherry ..... *Prunus serotina*
- Black walnut ..... *Juglans nigra*
- Boxelder ..... *Acer negundo*

[3] *The common and scientific names of tree species are based on: Little, Elbert L., Jr. Checklist of United States Trees (Native and Naturalized). Agric. Handb. 541. Washington, D.C: U.S. Department of Agriculture, Forest Service; 1979. 375 p.*

Other hardwoods
- Black locust ..... *Robinia pseudoacacia*
- Honeylocust ..... *Gleditsia triacanthos*
- Kentucky coffeetree ..... *Gymnocladus dioicus*
- Northern catalpa ..... *Catalpa speciosa*
- Common persimmon ..... *Diospyros virginiana*
- Red mulberry ..... *Morus rubra*
- River birch ..... *Betula nigra*
- Sugarberry ..... *Celtis laevigata*
- Texas buckeye ..... *Aesculus glabra* var. *arguta*

Noncommercial species
- Ailanthus ..... *Ailanthus altissima*
- Eastern redbud ..... *Cercis canadensis*
- Hawthorn ..... *Crataegus* spp.
- Osage-orange ..... *Maclura pomifera*
- Eastern hophornbeam ..... *Ostrya virginiana*

DEFINITION OF TERMS

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Commercial forest land.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of annual growth under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.) Also see definition of pastured commercial forest land.

Commercial species.—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

Cull.—Portions of a tree that are unusable for industrial wood products, because of rot, form, or other defect.

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note: Stocking is measured by comparison of basal area and/or number of trees, by age or size and spacing with specified standards). The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width at least 120 feet wide to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas shall be classed as forest if less than 120 feet in width. Also see definitions of land area, commercial forest land, noncommercial forest land, productive-reserved forest land, stocking, unproductive forest land, nonforest land, and water.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet in height at maturity.

Forest types.—A classification of forest land based upon the species forming a plurality of live tree stocking. Major forest types in Kansas are:

Eastern redcedar-hardwood.—Forests in which hardwoods comprise a plurality of the stocking but in which eastern redcedar comprises 25 percent or more of the stocking. Found on dry uplands, usually abandoned pastures or fields.

Oak-hickory.—Forests in which upland oaks (white, northern red, black) or hickory, singly or in combination, comprise a plurality of the stocking, except for stands classed as eastern redcedar-hardwood or as post-blackjack oak. Occurs on a variety of soils.

Post-blackjack oak.—Forests in which post oak or blackjack oak, singly or in combination, comprise a majority of the stocking. Occurs on dry uplands and ridges.

Upland plains hardwoods.—Forests in which black walnut, hackberry, and bur oak, singly or in combination, comprise a plurality of the stocking. Commonly found on slopes and uplands.

Elm-ash-cottonwood.—Lowland forest in which elm, ash, cottonwood, and willow, singly or in combination, comprise a plurality of the stocking, except for those in which cottonwood or willow comprise a majority of the stocking. Found on first or second bottoms of major streams.

Cottonwood.—Forests in which cottonwood comprises a majority of the stocking.

Willow.—Forests in which willow comprises a majority of the stocking.

Lowland plains hardwoods.—Forests in which black walnut, hackberry, bur oak, soft maple, and boxelder, singly or in combination, comprise a plurality of the stocking. Commonly found in coves and bottomlands.

Upland elm-ash-locust.—Upland forests in which elm, ash, and honeylocust, singly or in combination, comprise a plurality of the stocking. Includes shelterbelts and windbreaks on sites drier than those commonly associated with lowland species.

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem, or to the point where the central stem breaks into limbs. Cubic

feet can be converted to cords by multiplying by 79 cubic feet per solid wood cord.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Land area.—A. *Bureau of the Census.*—The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs estuaries, and canals less than ⅛of a statute mile in width; and lakes, reservoirs, and ponds less than 40 acres in area.

B. *Forest Inventory and Analysis.*—The same as the Bureau of the Census, except minimum width of streams, etc. is 120 feet and minimum size of lakes, etc. is 1 acre.

Noncommercial forest land.—(a) Unproductive forest land and (b) productive-reserved forest land. See definitions of unproductive and productive-reserved forest land.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality which normally do not develop into trees suitable for industrial wood products.

Nonforest land.—Land that has never supported forests, and lands formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and more than 1 acre in size, to qualify as nonforest land.)

A. *Nonforest land without trees.*—Nonforest land with no live trees present.

B. *Nonforest land with trees.*—Nonforest land with one or more trees at least 5 inches in d.b.h. per acre.

Nonstocked land.—Commercial forest land less than 16.7 percent stocked with growing-stock trees.

Other removals.—Growing-stock trees removed but not utilized for products, or trees left standing but "removed" from the commercial forest land classification by land use change. Examples are removals from cultural operations such as timber stand improvement work, land clearing, and changes in land use.

Pastured commercial forest land.—Commercial forest land for which the primary use is wood production, but is presently used for grazing.

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches in d.b.h., but smaller than sawtimber size.

Productive-reserved forest land.—Forest land sufficiently productive to qualify as commercial forest land, but withdrawn from timber utilization through statute, administration regulation, designation, or exclusive use for Christmas-tree production, as indicated by annual shearing.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Roundwood products.—Logs, bolts, or other round sections (including chips from roundwood) cut from trees for industrial or consumer uses. (Note: Includes saw logs; veneer logs and bolts; cooperage logs and bolts; pulpwood; fuelwood; piling; poles; posts; hewn ties; mine timbers; and various other round, split, or hewn products.)

Saw log.—A log meeting minimum standards of diameter, length and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by Regional standards.

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting Regional specifications for freedom from defect. Softwoods must be at least 9 inches in d.b.h. Hardwoods must be at least 11 inches in d.b.h.

Sawtimber volume.—Net volume of the saw log portion of live sawtimber in board feet, International ¼-inch rule, from stump to a minimum 7 inches top d.o.b. for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Short-log (rough tree).—Live trees of commercial species that contain one merchantable 8- to 11-foot saw log but not a 12-foot saw log or two noncontiguous saw logs 8 feet or longer now or prospectively.

Site index.—An expression of forest site quality based on the height of a free-growing dominant or codominant tree of a representative species in the forest type at age 50.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.—The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

Stand-size class.—A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber or seedlings and saplings.

Sawtimber stands.—Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

Poletimber stands.—Stands at least 16.7 percent stocked with growing-stock trees of which half or more of this stocking is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

Sapling-seedling stands.—Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the stocking is saplings and/or seedlings.

Nonstocked stands.—Stands in which stocking of growing-stock trees is less than 16.7 percent.

Timber removals from growing stock.—The volume of sound wood in growing-stock trees removed annually for forest products (including roundwood products and logging residues) and for other removals.

Timber removals from sawtimber.—The net board-foot volume of live sawtimber trees removed for forest productsannually (including roundwood products and logging residues) and for other removals.

Unproductive forest land.—Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soils, dry climate, poor drainage, high elevation, steepness, and rockiness.)

METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.

Table 3.--Timber removals from growing stock and sawtimber on commercial forest land by species group, Kansas, 1964 and 1980, and projected annual harvest, 1982-1991

Species group	Growing stock			Sawtimber		
	1964[1]	1980	Projected annual harvest 1982-1991	1964[1]	1980	Projected annual harvest 1982-1991
	Thousand cubic feet			Thousand board feet[2]		
Softwoods						
Eastern redcedar	21	89	42	--	324	120
Total	21	89	42	--	324	120
Hardwoods						
White oak	1,368	2,483	5,566	4,599	7,482	22,206
Red oak	648	1,898	2,434	1,624	5,728	10,621
Hickory	611	359	1,112	1,717	1,178	3,506
Hard maple	12	15	222	4	41	322
Soft maple	667	500	1,298	2,732	2,126	4,910
Ash	607	1,629	2,983	1,550	5,484	9,706
Cottonwood	1,120	1,935	12,685	4,183	9,154	43,797
Basswood	19	17	230	11	66	774
Elm	848	685	2,147	2,539	2,538	3,975
Black walnut	1,180	1,307	1,614	7,240	8,281	5,461
Hackberry	626	1,220	4,923	2,351	4,890	16,558
Sycamore	259	320	1,508	903	1,611	5,090
Other hardwoods[3]	314	1,526	3,676	547	4,350	6,161
Total	8,279	13,894	40,398	30,000	52,929	133,087
All species	8,300	13,983	40,440	30,000	53,253	133,207

[1] Figures have been adjusted from those published after the 1966 survey to conform to 1980 volumes because of changes in survey definitions and procedures.

[2] International 1/4-inch rule.

[3] Includes willow and boxelder species groups.

Table 4.--Timber removals from growing stock and sawtimber on commercial forest land by item and species category, Kansas, 1980

Item	All species	Softwoods	Oak	Elm-hackberry	Ash	Cottonwood	Walnut	Other hardwoods
				GROWING STOCK				
				Species category				
				Thousand cubic feet				
ROUNDWOOD PRODUCTS								
Saw logs	4,340	66	730	638	336	940	1,138	492
Veneer logs	72	--	12	--	--	--	60	--
Cooperage logs	40	--	40	--	--	--	--	--
Fuelwood	7,577	--	3,184	1,033	1,034	398	--	1,928
Posts	52	18	19	--	--	--	--	15
Total	12,081	84	3,985	1,671	1,370	1,338	1,198	2,435
LOGGING RESIDUE	755	--	231	69	137	140	109	69
OTHER REMOVALS	1,147	5	165	165	122	457	--	233
ALL TIMBER REMOVALS	13,983	89	4,381	1,905	1,629	1,935	1,307	2,737
				SAWTIMBER				
				Thousand board feet[1/]				
ROUNDWOOD PRODUCTS								
Saw logs	26,269	312	3,358	4,017	1,991	6,107	7,431	3,053
Veneer logs	475	--	59	--	--	--	416	--
Cooperage logs	237	--	237	--	--	--	--	--
Fuelwood	20,895	--	8,773	2,850	2,851	1,097	--	5,324
Posts	114	11	62	--	--	--	--	41
Total	47,990	323	12,489	6,867	4,842	7,204	7,847	8,418
LOGGING RESIDUE	1,637	--	327	125	315	293	434	143
OTHER REMOVALS	3,626	1	394	436	327	1,657	--	811
ALL TIMBER REMOVALS	53,253	324	13,210	7,428	5,484	9,154	8,281	9,372

[1/] International 1/4-inch rule.

Table 5.--Area of commercial forest land qualifying for treatment by forest type and treatment class, Kansas, 1982-1991

(In thousand acres)

Forest type	All classes	Treatment class: Harvest	Thinning	Stand conversion or restocking	No treatment
Eastern redcedar-hardwood	27.5	1.4	--	4.6	21.5
Post-blackjack oak	30.9	1.2	5.7	1.2	22.8
Oak-hickory	316.6	69.6	15.8	24.1	207.1
Upland elm-ash-locust	110.3	6.4	7.4	24.0	72.5
Upland plains hardwoods	49.4	4.8	4.9	1.1	38.6
Cottonwood	68.1	53.1	--	6.5	8.5
Willow	4.2	1.0	--	2.0	1.2
Lowland plains hardwoods	265.9	82.4	33.9	19.2	130.4
Elm-ash-cottonwood	289.6	73.3	38.2	19.8	158.3
Nonstocked	45.4	--	--	45.4	--
All types	1,207.9	293.2	105.9	147.9	660.9

Table 6.--Average annual area of commercial forest land qualifying for treatment by forest type, site-index class and treatment class, Kansas, 1982-1991

(In acres)

Forest type	All classes	Site-index class (feet)							
		21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
HARVEST									
Eastern redcedar-hardwood	138	--	138	--	--	--	--	--	--
Post-blackjack oak	122	--	--	--	122	--	--	--	--
Oak-hickory	6,964	--	125	1,247	2,518	1,561	1,178	335	--
Upland elm-ash-locust	639	--	--	96	203	247	93	--	--
Upland plains hardwoods	481	--	--	--	234	247	--	--	--
Cottonwood	5,309	--	--	175	1,274	1,867	1,509	365	119
Willow	97	--	--	--	--	97	--	--	--
Lowland plains hardwoods	8,244	--	138	211	1,758	3,286	2,303	548	--
Elm-ash-cottonwood	7,330	--	--	297	2,003	2,569	1,939	421	101
Nonstocked	--	--	--	--	--	--	--	--	--
All types	29,324	--	401	2,026	8,112	9,874	7,022	1,669	220
THINNING									
Eastern redcedar-hardwood	--	--	--	--	--	--	--	--	--
Post-blackjack oak	571	--	223	--	232	116	--	--	--
Oak-hickory	1,583	--	157	--	382	446	331	146	121
Upland elm-ash-locust	744	--	--	121	296	115	--	212	--
Upland plains hardwoods	488	--	--	--	115	101	115	157	--
Cottonwood	--	--	--	--	--	--	--	--	--
Willow	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	3,391	--	--	380	466	892	742	818	93
Elm-ash-cottonwood	3,816	--	--	--	248	1,167	1,013	746	642
Nonstocked	--	--	--	--	--	--	--	--	--
All types	10,593	--	380	501	1,739	2,837	2,201	2,079	856
STAND CONVERSION OR RESTOCKING									
Eastern redcedar-hardwood	463	186	120	--	157	--	--	--	--
Post-blackjack oak	123	--	--	--	--	--	123	--	--
Oak-hickory	2,401	--	225	366	963	375	344	128	--
Upland elm-ash-locust	2,399	--	560	712	599	132	396	--	--
Upland plains hardwoods	110	--	--	--	110	--	--	--	--
Cottonwood	653	--	--	254	--	399	--	--	--
Willow	204	--	--	121	--	--	83	--	--
Lowland plains hardwoods	1,914	--	--	157	144	1,137	319	157	--
Elm-ash-cottonwood	1,980	--	--	271	638	574	497	--	--
Nonstocked	4,540	--	390	1,130	980	1,430	360	250	--
All types	14,787	186	1,295	3,011	3,591	4,047	2,122	535	--

Table 7.--Average annual area of commercial forest land qualifying for treatment by forest type, stand-age class and treatment class, Kansas, 1982-1991

(In acres)

Forest type	All classes	Stand-age class (years)												
		0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
HARVEST														
Eastern redcedar-hardwood	138	--	--	--	--	--	--	--	--	--	--	--	138	--
Post-blackjack oak	122	--	--	--	--	--	--	--	--	--	--	122	--	--
Oak-hickory	6,964	--	--	--	--	--	--	--	--	1,513	1,495	2,555	1,171	230
Upland elm-ash-locust	639	--	--	--	--	--	--	--	--	220	202	96	121	--
Upland plains hardwoods	481	--	--	--	--	--	--	--	--	115	--	119	247	--
Cottonwood	5,309	--	--	--	--	727	661	1,575	810	229	673	634	--	--
Willow	97	--	--	--	--	--	97	--	--	--	--	--	--	--
Lowland plains hardwoods	8,244	--	--	--	--	--	--	--	3,747	1,420	1,987	869	119	102
Elm-ash-cottonwood	7,330	--	--	--	--	--	--	--	2,697	2,689	1,338	606	--	--
Nonstocked	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	29,324	--	--	--	--	727	758	1,575	7,254	6,186	5,695	5,001	1,796	332
THINNING														
Eastern redcedar-hardwood	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Post-blackjack oak	571	--	--	--	339	232	--	--	--	--	--	--	--	--
Oak-hickory	1,583	--	--	--	614	969	--	--	--	--	--	--	--	--
Upland elm-ash-locust	744	--	--	--	532	--	115	97	--	--	--	--	--	--
Upland plains hardwoods	488	--	--	--	488	--	--	--	--	--	--	--	--	--
Cottonwood	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Willow	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	3,391	--	--	--	1,443	331	1,617	--	--	--	--	--	--	--
Elm-ash-cottonwood	3,816	--	--	--	1,618	367	1,831	--	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	10,593	--	--	--	5,034	1,899	3,563	97	--	--	--	--	--	--
STAND CONVERSION OR RESTOCKING														
Eastern redcedar-hardwood	463	278	185	--	--	--	--	--	--	--	--	--	--	--
Post-blackjack oak	123	--	--	--	--	--	--	--	123	--	--	--	--	--
Oak-hickory	2,401	447	1,017	246	122	115	128	101	225	--	--	--	--	--
Upland elm-ash-locust	2,399	1,777	138	132	--	--	97	140	115	--	--	--	--	--
Upland plains hardwoods	110	--	--	--	--	--	--	110	--	--	--	--	--	--
Cottonwood	653	--	--	--	53	214	--	132	254	--	--	--	--	--
Willow	204	121	--	83	--	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	1,914	95	210	--	--	214	--	771	624	--	--	--	--	--
Elm-ash-cottonwood	1,980	240	885	128	123	128	319	--	157	--	--	--	--	--
Nonstocked	4,540	1,310	750	720	380	--	699	210	381	90	--	--	--	--
All types	14,787	4,268	3,185	1,309	678	671	1,243	1,464	1,879	90	--	--	--	--

Table 8.--Average annual growing-stock removals on commercial forest land qualifying for treatment by forest type, site-index class and treatment class, Kansas, 1982-1991

(In thousand cubic feet)

Forest type	All classes	Site-index class (feet)							
		21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
HARVEST									
Eastern redcedar-hardwood	129.2	--	129.2	--	--	--	--	--	--
Post-blackjack oak	99.3	--	--	--	99.3	--	--	--	--
Oak-hickory	7,610.4	--	89.0	947.3	2,504.4	1,865.2	1,786.0	418.5	--
Upland elm-ash-locust	593.0	--	--	61.5	163.4	279.0	89.1	--	--
Upland plains hardwoods	485.9	--	--	--	168.6	317.3	--	--	--
Cottonwood	11,116.8	--	--	94.0	2,011.2	3,047.0	4,014.8	1,372.2	577.6
Willow	35.7	--	--	--	--	35.7	--	--	--
Lowland plains hardwoods	10,923.1	--	133.8	149.1	1,852.7	4,440.0	3,097.6	1,249.9	--
Elm-ash-cottonwood	9,446.4	--	--	119.3	1,634.6	3,104.9	3,482.1	649.3	456.2
Nonstocked	--	--	--	--	--	--	--	--	--
All types	40,439.8	--	352.0	1,371.2	8,434.2	13,089.1	12,469.6	3,689.9	1,033.8
THINNING									
Eastern redcedar-hardwood	--	--	--	--	--	--	--	--	--
Post-blackjack oak	272.6	--	88.7	--	129.8	54.1	--	--	--
Oak-hickory	1,241.4	--	35.3	--	346.6	210.9	406.7	108.4	133.5
Upland elm-ash-locust	277.6	--	--	59.4	52.3	56.6	--	109.3	--
Upland plains hardwoods	280.4	--	--	--	56.1	43.2	33.2	147.9	--
Cottonwood	--	--	--	--	--	--	--	--	--
Willow	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	1,412.5	--	--	121.0	143.3	374.6	267.1	409.8	96.7
Elm-ash-cottonwood	2,388.3	--	--	--	136.1	417.0	726.3	553.8	555.1
Nonstocked	--	--	--	--	--	--	--	--	--
All types	5,872.8	--	124.0	180.4	864.2	1,156.4	1,433.3	1,329.2	785.3
STAND CONVERSION OR RESTOCKING									
Eastern redcedar-hardwood	27.6	13.0	4.5	--	10.1	--	--	--	--
Post-blackjack oak	53.1	--	--	--	--	--	53.1	--	--
Oak-hickory	514.4	--	24.2	26.3	128.9	67.4	217.8	49.8	--
Upland elm-ash-locust	401.7	--	28.0	153.2	87.5	--	133.0	--	--
Upland plains hardwoods	63.0	--	--	--	63.0	--	--	--	--
Cottonwood	294.3	--	--	124.6	--	169.7	--	--	--
Willow	29.5	--	--	--	--	--	29.5	--	--
Lowland plains hardwoods	970.6	--	--	57.8	94.7	511.5	206.1	100.5	--
Elm-ash-cottonwood	721.2	--	--	20.1	149.2	147.8	404.1	--	--
Nonstocked	359.1	--	--	67.2	64.7	195.6	31.6	--	--
All types	3,434.5	13.0	56.7	449.2	598.1	1,092.0	1,075.2	150.3	--

Table 9.--Average annual growing-stock removals on commercial forest land qualifying for treatment by forest type, stand-age class, and treatment class, Kansas, 1982-1991

(In thousand cubic feet)

Forest type	All classes	Stand-age class (years) 0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
HARVEST														
Eastern redcedar-hardwood	129.2	--	--	--	--	--	--	--	--	--	--	--	129.2	--
Post-blackjack oak	99.3	--	--	--	--	--	--	--	--	--	--	99.3	--	--
Oak-hickory	7,610.4	--	--	--	--	--	--	--	--	1,611.1	2,148.7	2,622.8	1,065.2	162.6
Upland elm-ash-locust	593.0	--	--	--	--	--	--	--	--	247.1	163.4	61.5	121.0	--
Upland plains hardwoods	485.9	--	--	--	--	--	--	--	--	118.7	--	49.9	317.3	--
Cottonwood	11,116.8	--	--	--	--	1,297.2	963.6	3,358.7	1,261.2	601.7	2,178.5	1,455.9	--	--
Willow	35.7	--	--	--	--	--	35.7	--	--	--	--	--	--	--
Lowland plains hardwoods	10,923.1	--	--	--	--	--	--	--	5,037.1	2,029.5	2,188.4	1,318.7	117.1	232.3
Elm-ash-cottonwood	9,446.4	--	--	--	--	--	--	--	3,822.7	2,955.7	1,512.1	1,155.9	--	--
Nonstocked	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	40,439.8	--	--	--	--	1,297.2	999.3	3,358.7	10,121.0	7,563.8	8,191.1	6,764.0	1,749.8	394.9
THINNING														
Eastern redcedar-hardwood	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Post-blackjack oak	272.6	--	--	--	135.5	137.1	--	--	--	--	--	--	--	--
Oak-hickory	1,241.4	--	--	--	626.1	615.3	--	--	--	--	--	--	--	--
Upland elm-ash-locust	277.6	--	--	--	168.2	--	32.0	77.4	--	--	--	--	--	--
Upland plains hardwoods	280.4	--	--	--	280.4	--	--	--	--	--	--	--	--	--
Cottonwood	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Willow	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	1,412.5	--	--	--	512.6	99.2	800.7	--	--	--	--	--	--	--
Elm-ash-cottonwood	2,388.3	--	--	--	745.6	198.4	1,444.3	--	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	5,872.8	--	--	--	2,468.4	1,050.0	2,277.0	77.4	--	--	--	--	--	--
STAND CONVERSION OR RESTOCKING														
Eastern redcedar-hardwood	27.6	14.6	13.0	--	--	--	--	--	--	--	--	--	--	--
Post-blackjack oak	53.1	--	--	--	--	--	--	--	53.1	--	--	--	--	--
Oak-hickory	514.4	28.7	129.6	41.3	13.3	51.5	35.8	71.2	143.0	--	--	--	--	--
Upland elm-ash-locust	401.7	234.1	18.5	--	--	--	30.0	48.0	71.1	--	--	--	--	--
Upland plains hardwoods	63.0	--	--	--	--	--	--	63.0	--	--	--	--	--	--
Cottonwood	294.3	--	--	--	17.7	93.0	--	59.0	124.6	--	--	--	--	--
Willow	29.5	--	--	29.5	--	--	--	--	--	--	--	--	--	--
Lowland plains hardwoods	970.6	17.6	52.9	--	--	109.6	--	432.7	357.8	--	--	--	--	--
Elm-ash-cottonwood	721.2	26.0	183.9	39.6	17.9	56.0	257.1	--	140.7	--	--	--	--	--
Nonstocked	359.1	51.3	23.0	56.6	60.3	--	66.5	31.6	39.4	30.4	--	--	--	--
All types	3,434.5	372.3	420.9	167.0	109.2	310.1	389.4	705.5	929.7	30.4	--	--	--	--

Table 10.- Average annual growing-stock and sawtimber removals on commercial forest land qualifying for treatment by forest type and treatment class, Kansas, 1982-1991

Forest type	Growing stock			Sawtimber		
	Harvest	Thinning	Restocking	Harvest	Thinning	Restocking
	Thousand cubic feet			Thousand board feet		
Eastern redcedar-hardwood	129.2	--	27.6	308.8	--	--
Post-blackjack oak	99.3	272.6	53.1	348.1	--	253.1
Oak-hickory	7,610.4	1,241.4	514.4	26,485.7	393.7	1,258.3
Upland elm-ash-locust	593.0	277.6	401.7	1,325.2	243.9	773.0
Upland plains hardwoods	485.9	280.4	63.0	1,149.3	--	220.2
Cottonwood	11,116.8	--	294.3	37,545.8	--	1,061.9
Willow	35.7	--	29.5	84.7	--	34.8
Lowland plains hardwoods	10,923.1	1,412.5	970.6	37,213.4	1,121.7	3,032.1
Elm-ash-cottonwood	9,446.4	2,388.3	721.2	28,745.8	2,736.9	1,978.9
Nonstocked	--	--	359.1	--	--	736.9
All types	40,439.8	5,872.8	3,434.5	133,206.8	4,496.2	9,349.2

Table 11.--Average annual growing-stock and sawtimber removals on commercial forest land qualifying for treatment by species group, tree class, and treatment class, Kansas, 1982-1991

Species group	Total all live	Growing stock		Short-log	Rough and rotten cull	Sawtimber	Short-log
		Poletimber	Sawtimber				
	Thousand cubic feet					Thousand board feet[1/]	
HARVEST							
Eastern redcedar	41.9	20.4	21.5	--	--	120.8	--
White oak	6,313.9	616.5	4,949.2	337.3	410.9	22,206.2	716.8
Red oak	2,569.6	179.6	2,254.6	31.7	103.7	10,621.2	109.0
Hickory	1,188.8	327.9	784.4	37.0	39.5	3,506.4	143.6
Basswood	272.8	80.5	149.6	7.9	34.8	773.5	26.8
Hard maple	229.4	150.1	71.6	5.6	2.1	321.5	17.5
Soft maple	1,385.3	113.4	1,184.9	37.5	49.5	4,909.8	101.6
Elm	2,447.9	1,282.3	864.9	106.2	194.5	3,974.9	304.3
Ash	3,287.5	913.8	2,068.9	149.6	155.2	9,705.7	440.8
Sycamore	1,519.8	79.8	1,428.0	--	12.0	5,089.9	--
Cottonwood	13,005.9	725.6	11,959.1	212.1	109.1	43,796.6	582.8
Willow	509.0	127.1	314.7	18.9	48.3	1,353.8	55.9
Hackberry	5,320.0	1,234.8	3,687.8	231.9	165.5	16,557.6	710.1
Black cherry	26.4	7.8	17.0	--	1.6	85.6	--
Black walnut	1,698.2	502.0	1,111.7	46.7	37.8	5,460.5	145.0
Boxelder	736.1	419.9	150.0	15.5	150.7	661.0	48.3
Other hardwoods	2,983.5	1,598.4	895.7	134.5	354.9	4,061.8	413.8
Noncommercial	146.3	146.3	--	--	--	--	--
All species	43,682.3	8,526.2	31,913.6	1,372.4	1,870.1	133,206.8	3,816.3
THINNING							
Eastern redcedar	8.1	8.1	--	--	--	--	--
White oak	836.3	683.2	23.5	81.0	48.6	104.4	203.3
Red oak	422.9	280.5	34.2	91.0	17.2	128.0	309.4
Hickory	401.7	299.8	48.1	30.9	22.9	230.4	99.7
Basswood	42.4	7.2	21.5	13.7	--	107.7	50.6
Hard maple	43.3	33.3	10.0	--	--	47.5	--
Soft maple	132.7	39.0	57.4	31.5	4.8	289.4	89.5
Elm	764.9	588.2	83.2	37.9	55.6	377.0	119.2
Ash	889.7	568.9	210.6	58.9	51.3	1,038.4	186.3
Sycamore	178.5	--	177.6	--	0.9	677.8	--
Cottonwood	14.7	--	--	7.8	6.9	--	9.0
Willow	107.3	21.9	32.9	6.1	46.4	167.4	19.0
Hackberry	539.1	389.7	30.1	76.8	42.5	147.0	222.4
Black cherry	49.2	48.0	--	--	1.2	--	--
Black walnut	325.8	261.1	16.3	32.0	16.4	77.7	96.6
Boxelder	577.0	432.2	18.4	38.4	88.0	81.7	120.6
Other hardwoods	1,865.3	1,174.2	228.7	73.8	388.6	1,021.8	222.3
Noncommercial	46.4	45.0	--	--	1.4	--	--
All species	7,245.3	4,880.3	992.5	579.8	792.7	4,496.2	1,747.9
STAND CONVERSION OR RESTOCKING							
Eastern redcedar	74.9	38.4	33.4	3.1	--	185.5	56.7
White oak	319.0	54.3	252.5	7.9	4.3	1,164.8	12.8
Red oak	136.1	23.2	100.2	6.9	5.8	453.4	23.1
Hickory	246.7	109.3	109.8	--	27.6	478.8	--
Basswood	--	--	--	--	--	--	--
Hard maple	--	--	--	--	--	--	--
Soft maple	--	--	--	--	--	--	--
Elm	355.8	245.2	49.0	21.0	40.6	223.4	64.3
Ash	200.1	95.2	69.6	9.2	26.1	333.5	28.3
Sycamore	149.5	29.6	119.9	--	--	484.3	--
Cottonwood	568.9	50.9	506.6	10.8	0.6	2,103.9	24.2
Willow	156.9	38.2	118.7	--	--	537.3	--
Hackberry	330.8	94.0	184.7	37.6	14.5	916.6	103.7
Black cherry	28.5	8.0	14.8	5.7	--	61.3	18.0
Black walnut	442.0	118.5	284.1	39.4	--	1,384.2	118.9
Boxelder	204.8	84.3	42.0	5.3	73.2	172.4	16.9
Other hardwoods	749.8	351.6	187.4	15.7	195.1	849.8	48.8
Noncommercial	21.1	21.1	--	--	--	--	--
All species	3,984.9	1,361.8	2,072.7	162.6	387.8	9,349.2	515.7

[1/] International 1/4-inch rule.

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Smith, W. Brad; Moyer, W. J.
Forest treatment opportunities for Kansas 1982-1991. Res. Pap. NC-255. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 15 p.

Reviews treatment opportunities for timber stands in Kansas from 1982 to 1991. Under the assumptions and management guides specified, 45 percent of Kansas' commercial forest land would benefit from timber harvest or some other form of treatment during the decade.

KEY WORDS: Forest management, timber harvest, growing-stock volume, board-foot volume, commercial forest.

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Research
Paper **NC-256**

Anemometer Performance at Fire-weather Stations

Donald A. Haines and John S. Frost

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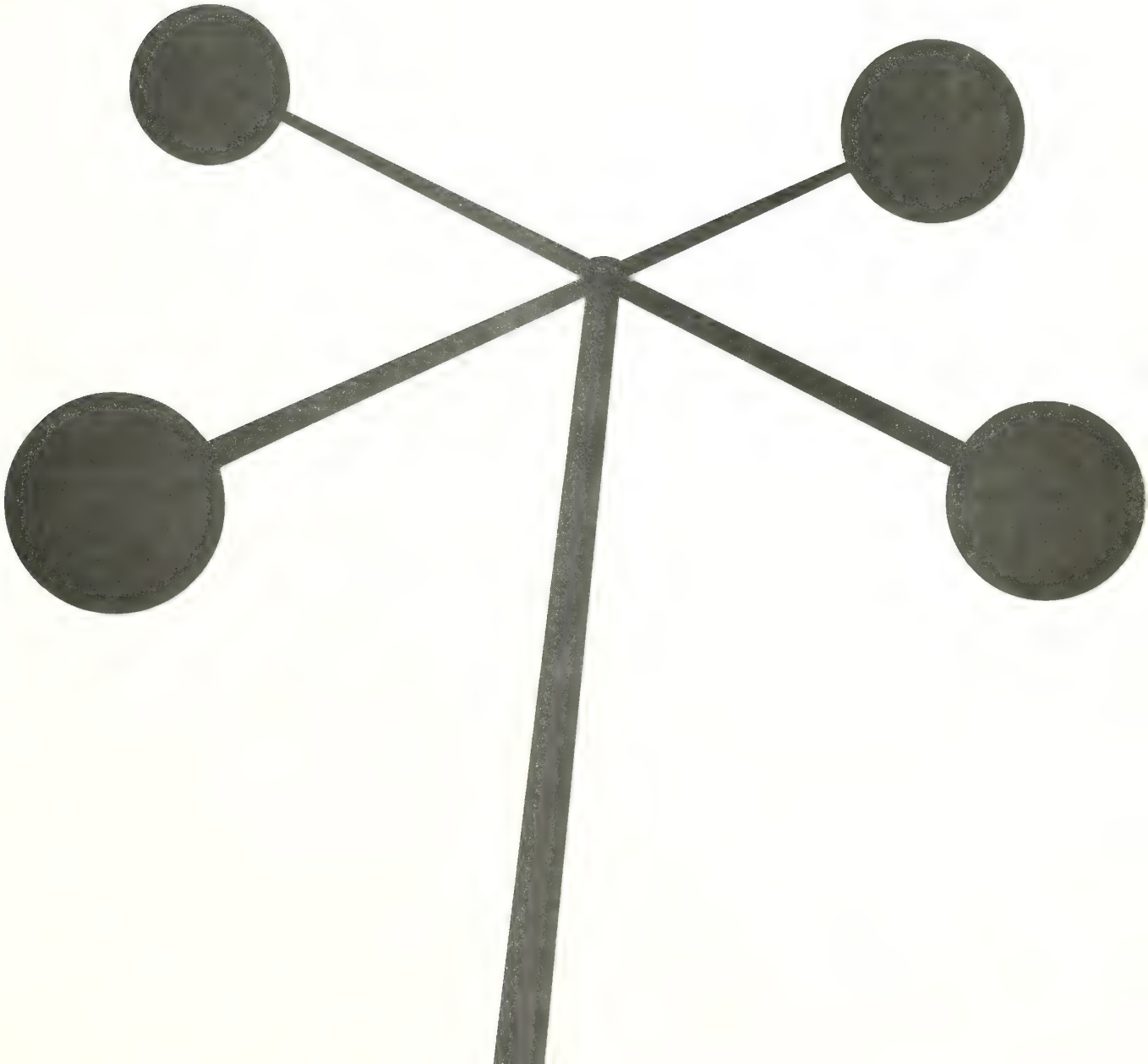

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ANEMOMETER PERFORMANCE AT FIRE-WEATHER STATIONS

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Wind speed measurements are critical when computing wildland fire-danger rating and predicting fire-behavior. A sensitivity analysis of the Rothermel (1972) rate-of-spread model showed that in a category of 11 variables, wind speed ranked first (Sanderlin and Sunderson 1975). For grass fuel models, an 18 percent wind speed error over the range 6 to 13 m/s results in a 40 percent error in predicted rate of spread (Kessell *et al.* 1977).

Unfortunately, fire-weather forecasters and fire-behavior specialists have no way of determining the accuracy of wind speed observations at fire-weather stations. A survey in the Northeastern United States indicated that field maintenance of anemometers ranged from fair to good, but that testing of the instruments was virtually nonexistent (Frost and Haines 1982). Because wind speed measurements significantly affect fire-behavior predictions and fire-danger ratings, we developed a portable instrument to test field anemometers (Haines *et al.* 1980). Since then we have checked the performance of anemometers at fire-weather stations throughout the Northeastern United States. This is a report of our findings.

METHODS

Approximately 250 forestry stations in the 21-State, Northeastern Region make fire-weather observations. The USDA Forest Service North Central Forest Experiment Station, the National Forest System, and Northeastern Area State and Private Forestry cooperate in a station inspection and a National Fire-Danger Rating System implementation program. As part of this program, a meteorological technician visits most of these stations on a 2-year rotating basis. The data for this paper were collected between January 1979 and January 1982 during these inspection visits and include detailed reports of 142 anemometers.

The following are the types of anemometers most often used at fire-weather stations in the Northeast:

Model[1]	Percent of use
M. C. Stewart aluminum-cup	55
Forester 9 x 145	25
Small Airways Model	16
Natural Power Model A75-104	4

We purchased three M. C. Stewart, two Forester 9 ×145, and one each of the other two anemometers (fig. 1), and calibrated them in wind tunnels.[2] The wind tunnel response of all three M. C. Stewart anemometers was essentially the same, therefore, we will show the error and calibration curves for just one of these units (figs. 2 and 3)[3] . The two Forester 9 ×145 units displayed differences in initial wind tunnel tests, therefore, we had them retested. The air flow accelerated near this anemometer due to its large size relative to the cross-sectional areas of the wind tunnels. Calculations showed that the tunnel speed in the vicinity of this anemometer was 1.04 times the speed measured by a pitot static tube, consequently, the reported data were corrected using this ratio.

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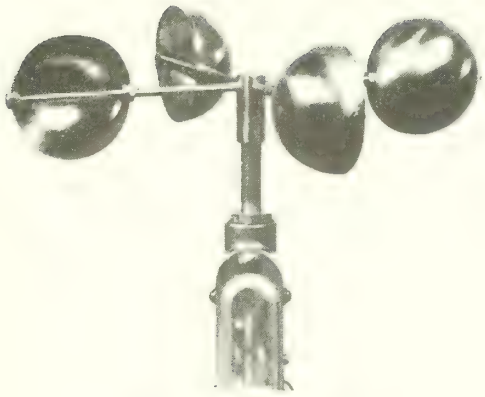
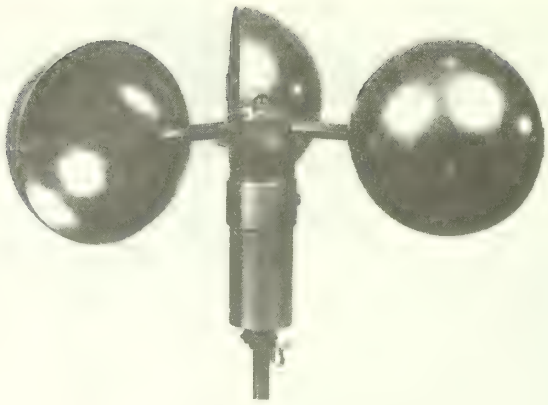
[1]*Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*

[2]*Anemometers were calibrated by: Hassan M. Nagib, Armour College of Engineering, Illinois Institute of Technology, Chicago, IL; Robert C. Nelson, Department of Aerospace and Mechnical Engineering, University of Notre Dame, Notre Dame, IN.*

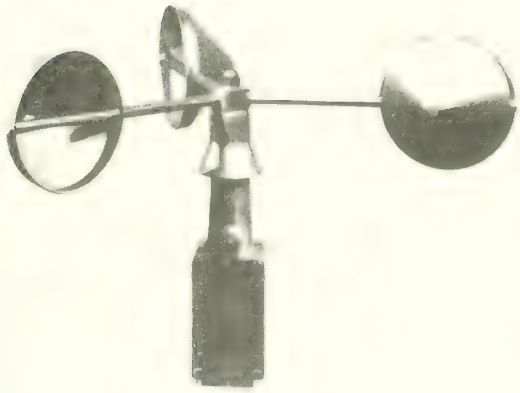
[3]*Operational results are given in miles per hour and meters per second. Metric units satisfy requirements specified in the International Systems of Units; but fire-weather observers report their observations in miles per hour.*



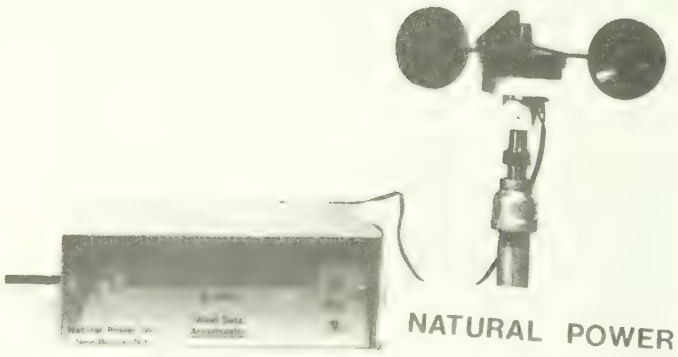
M.C. STEWART



FORESTER 9 x 145



AIRWAYS



NATURAL POWER

Figure 1.—*The four types of evaluated anemometers.*

The Airways and Natural Power anemometers displayed a negative error response over the entire range of tested velocities. The M. C. Stewart was negative below 15 m/s while the Forester 9 ×145 was positive over the tested range (fig. 2). As one might expect, the greatest change in the error curves occurred at low wind speeds. At higher velocities, the change in error was relatively uniform in most cases.

Before going to field stations, extensive tests were conducted to determine how accurately our portable equipment measured the wind speeds of the calibrated M. C. Stewart and Forester 9 ×145 anemometers (fig. 4). When testing the M. C. Stewart with this equipment, over a range of wind speeds from 2.2 to 9.0 m/s, maximum error was ±0.13 m/s at 9.0 m/s; ±0.09 at 4.5 and 7.0 m/s; and ±0.04 at 2.2 m/s. With the Forester 9 ×145 anemometer, the maximum error was ±0.04 m/s over the full range of considered wind speed. Therefore, we were confident that our equipment operated within the accuracy range required to check the performance of field anemometers.

RESULTS

We tested the M. C. Stewart and Airways anemometers at 2.2 m/s (5 mph) increments to 9.0 m/s (20 mph). Because of the large size of the Forester 9 ×145 relative to our equipment, we were unable to test its performance over the same range; its highest tested speed was 6.3 m/s (14 mph). The Natural Power anemometers were installed a short time before the study began, and all those tested conformed to the calibration standard (fig. 3). The deviations from ideal shown for the three anemometer types include both the wind-tunnel calibration error and the error identified during the field tests of individual anemometers. The calibration error is included because we found that the observers were not applying manufacturer specified corrections to their reported observations. Therefore, both error sources are incorporated in documented records.

Deviations from ideal wind speeds for the M. C. Stewart anemometers were most commonly -0.4 m/s

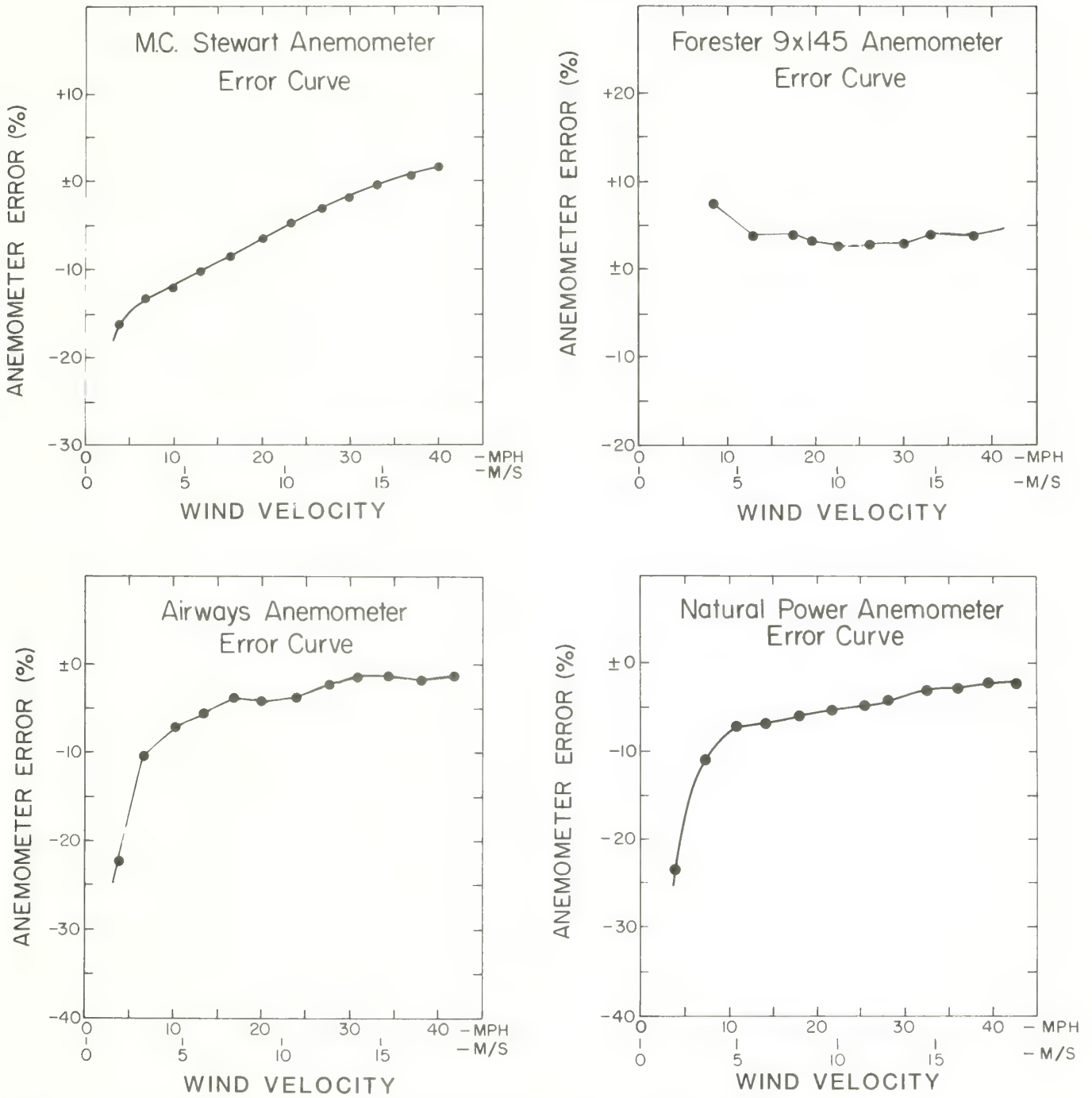


Figure 2.—*Error curves from wind tunnel calibrations for each anemometer type.*

(-1 mph) (42 to 63 percent of M. C. Stewart test results were in this category) (fig. 5). At wind speeds of 4.5, 7.0, and 9.0 m/s, 28 to 32 percent of the deviations were -0.9 m/s (-2 mph). The widest range of deviations occurred at the lowest tested wind speed, 2.2 m/s (5 mph). Here deviations ranged from 0.4 to -2.2 m/s (1 to -5 mph); the latter value resulted because some anemometer cups did not turn at low wind speeds.

Deviations from ideal for the Airways anemometer were concentrated at -0.4 m/s (-1 mph) over the full range of tested wind speeds (fig. 6). This anemometer was the most consistent of those tested.

Forester 9 ×145 tests were conducted at 2.2, 4.5, and 6.3 m/s (fig. 7). Most (89 percent) of the tested anemometers did not deviate from ideal at lower wind speeds; at the highest tested wind speed these anemometers showed a 0.4 m/s (1 mph) deviation from ideal.

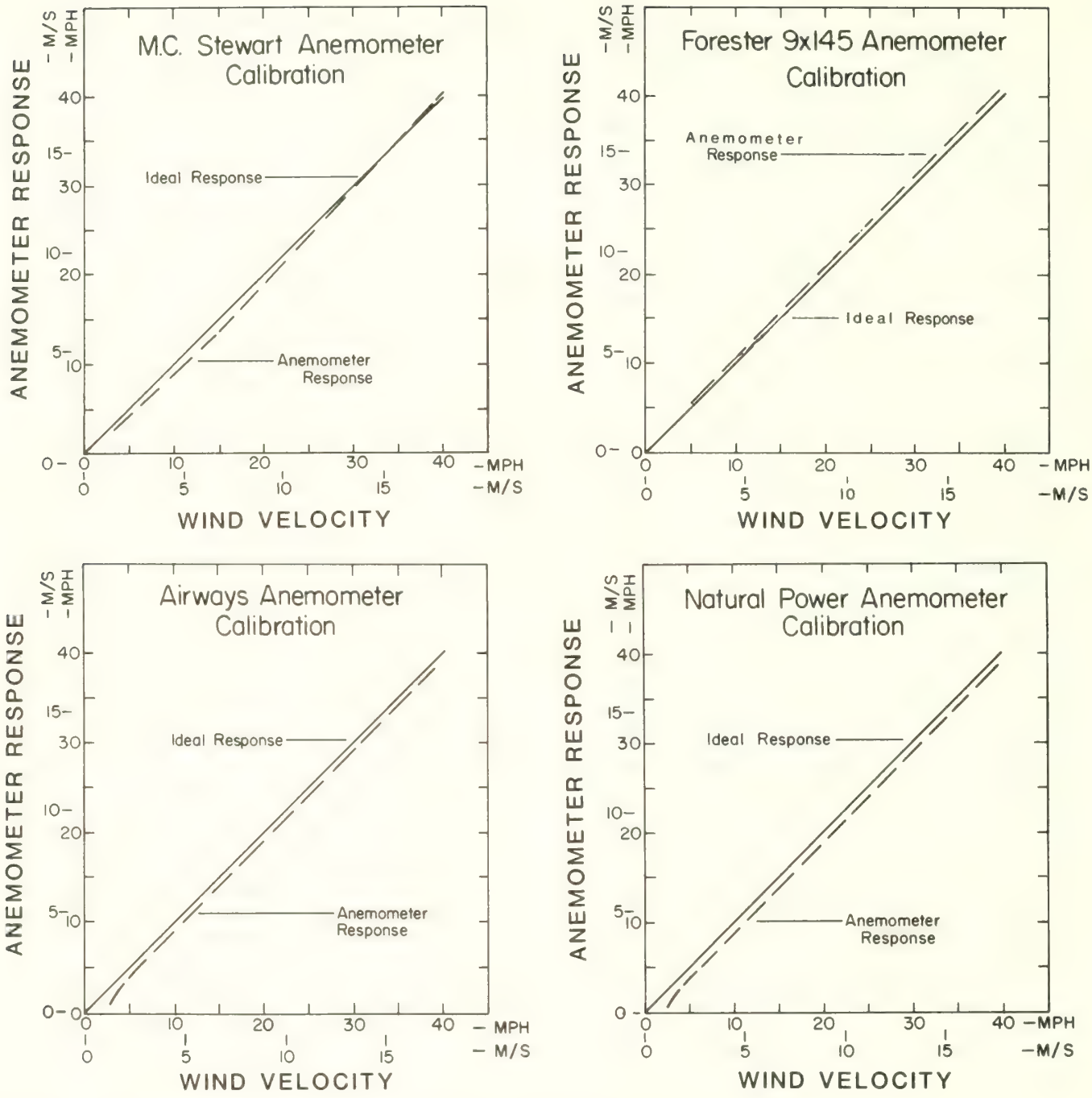


Figure 3.—*Wind tunnel calibration curves for each anemometer type.*

Of the tested units, 29 (20 percent) failed to respond with measurements within 10 percent of the wind tunnel calibrated anemometers at one or more test wind speeds. These units were either replaced or repaired. There was no significant failure difference among the three anemometer types; all failed roughly in proportion to the number surveyed. An examination of the failure rate as a function of time showed no discernible trend, but this may be a problem of a number of factors including sample size. It is readily apparent why field anemometer readings may deviate from the standard. Poor maintenance, for example, may result in excessive wear and cause increased friction on moving parts. Damaged parts, including bent or loose cups as well as bent spindles, may also result in changes in recorded wind speeds.

To the best of our knowledge, this is the first study to summarize information from a large number of field anemometers, some in use for many years. One-third of the Stewart anemometers were less than 4 years of age, while 45 percent were in service from 4

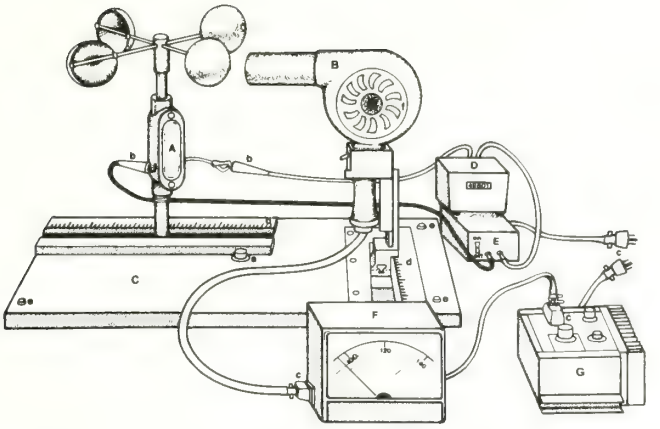


Figure 4.—*The anemometer tester includes: (A) anemometer to be tested, (B) industrial blower, (C) 12" ×21" solid testing board, (D) 12 volt DC counter, (E) 12 volt regulated DC power supply, (F) line voltage monitor, (G) variable voltage controller, (a) bubble level, (b) connections to counter, (c) electrical plugs, (d) tracks with metal measures, (e) level adjustment screws, and (f) blower manifold. Track mountings for the blower and the test anemometer permit both horizontal and vertical movement. The operator can generate a range of wind speeds by varying the distance between the blower and the anemometer and/or changing the air intake which is controlled by the blower manifold.*

to 9 years, and 22 percent for 10 or more years. The oldest unit was in use for more than 25 years. The Airways model has not been manufactured in the last 10 years, therefore, all units are at least that age. The Natural Power units were in place for no more than 2 years. The ages of the Forester anemometers were uniformly scattered from 1 to 9 years with only four units more than 10 years old. As with the failure survey, we did not see a well-defined trend in performance decline with years of service, but the effects of age are partially masked by a number of factors. Some anemometers are used throughout the year, while others are used only during the fire season; some are well maintained and properly lubricated, while others are not. Also, age assessments were estimates in a number of cases.

Given the deviations from ideal wind speeds generated by the two error terms, what is the impact on the calculated values of wildfire spread rates? Spread rate is usually defined in the context of a fuel model. Fuel model E (a part of the National Fire-Danger Rating System; Deeming *et al.* 1977) is a representative model for common fuels in the Northeastern United States. If we assume dead fine fuels and a relative humidity of 25 percent, then at a wind speed of 4.5 m/s (10 mph) negative deviations from the ideal of only 0.4 to 0.9 m/s (1 to 2 mph) will underpredict model E spread rates by 13 to 25 percent. At 9.0 m/s (20 mph) these same negative deviations from ideal will underpredict spread rates by 7 to 14 percent. Obviously these error terms are most important at lower wind speeds.

CONCLUSIONS AND RECOMMENDATIONS

Given that the field anemometer is continuously exposed to the worst of weather conditions, these instruments performed well year after year. None of the types tested proved unsatisfactory for use at fire-weather stations.

The Airways model has not been manufactured for some years; but given its proven durability, we expect that those units now in service will continue to perform for many years.

The M. C. Stewart wears somewhat faster than the other models, but is inexpensive and totally satisfactory for use at fire-weather stations. We note one word of caution with this anemometer; the contact points tend to wear quickly. This problem is solved by spending an additional few dollars and ordering the unit with a magnet-reed switch.

The Forester 9 ×145 model is more expensive than the other types tested, but the data indicate that it is sturdy and performs well in the field.

The Natural Power model appears somewhat fragile, and as yet it has not been subjected to the long-term rigors of the other three types. However, some units now have been in use at Northeastern field locations more than 4 years and as of this writing are performing satisfactorily.

Our inspections and survey disclosed that observers are not using calibration curves to correct wind speed observations. To assist in remedying this problem, we include the corrections obtained when calibrating our units (table 1).

This study was concerned with two error sources in anemometer performance. MacCready (1966) has documented other possibilities. Major wind-velocity reporting errors can also occur if the anemometer is not exposed properly (Fischer and Hardy 1972, Albini and Baughman 1979). And, even if all sources of anemometer and exposure error are properly addressed, one important factor remains: the ratio of forest to airport wind speeds ranges from 0.4 to 0.7, with a typical value of 0.5 (Simard 1969, Silversides 1978). Fire-weather forecasters located at airports must adjust their wind forecasts for this difference.

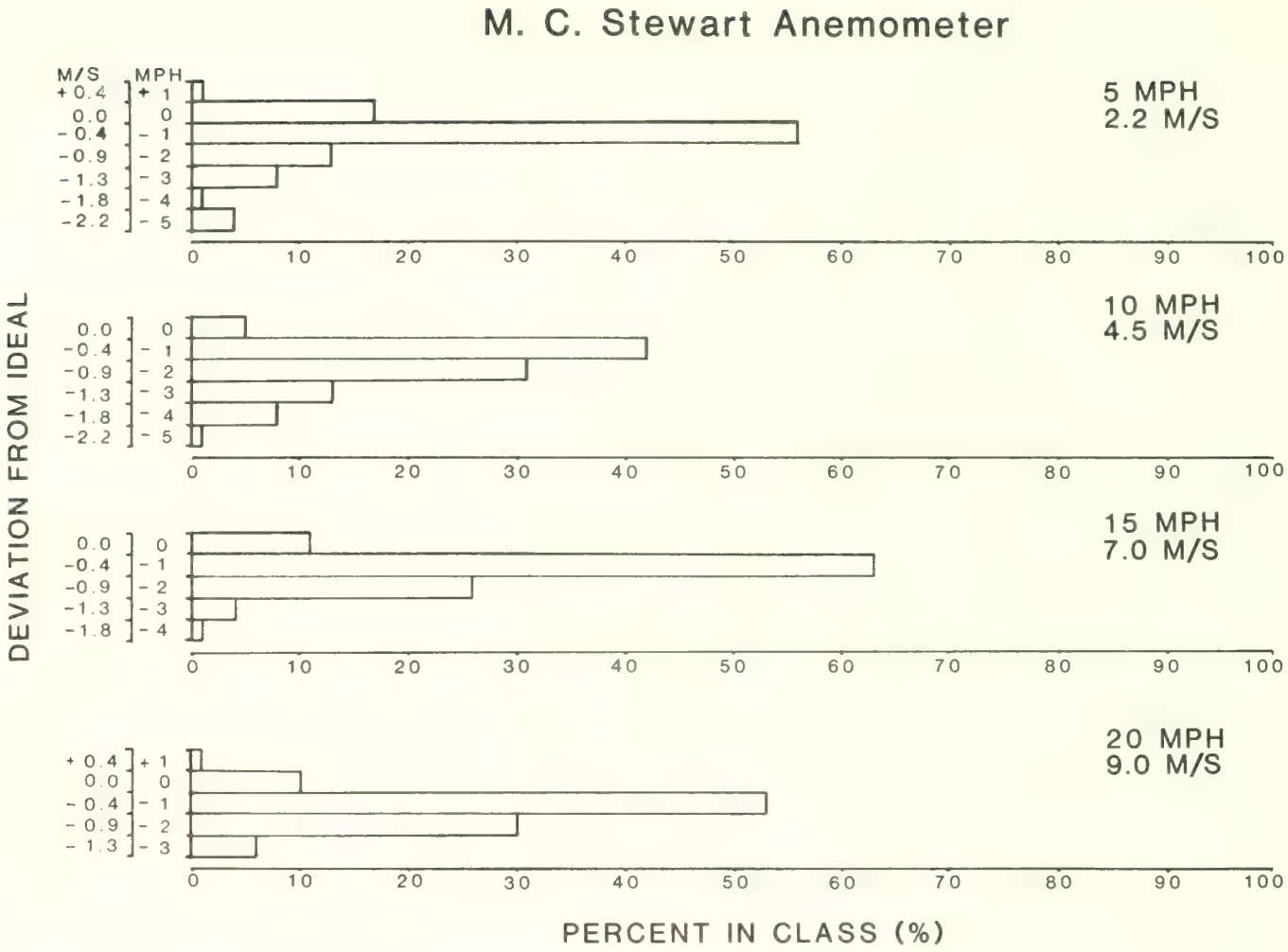


Figure 5.—*Deviations of the M. C. Stewart anemometer from ideal at four wind speeds. Data are grouped within a 0.4 m/s (1 mph) range. The groups include two error sources, the wind tunnel calibration difference and the error difference between the individual field units and the calibrated anemometers. Seventy-eight instruments were tested.*

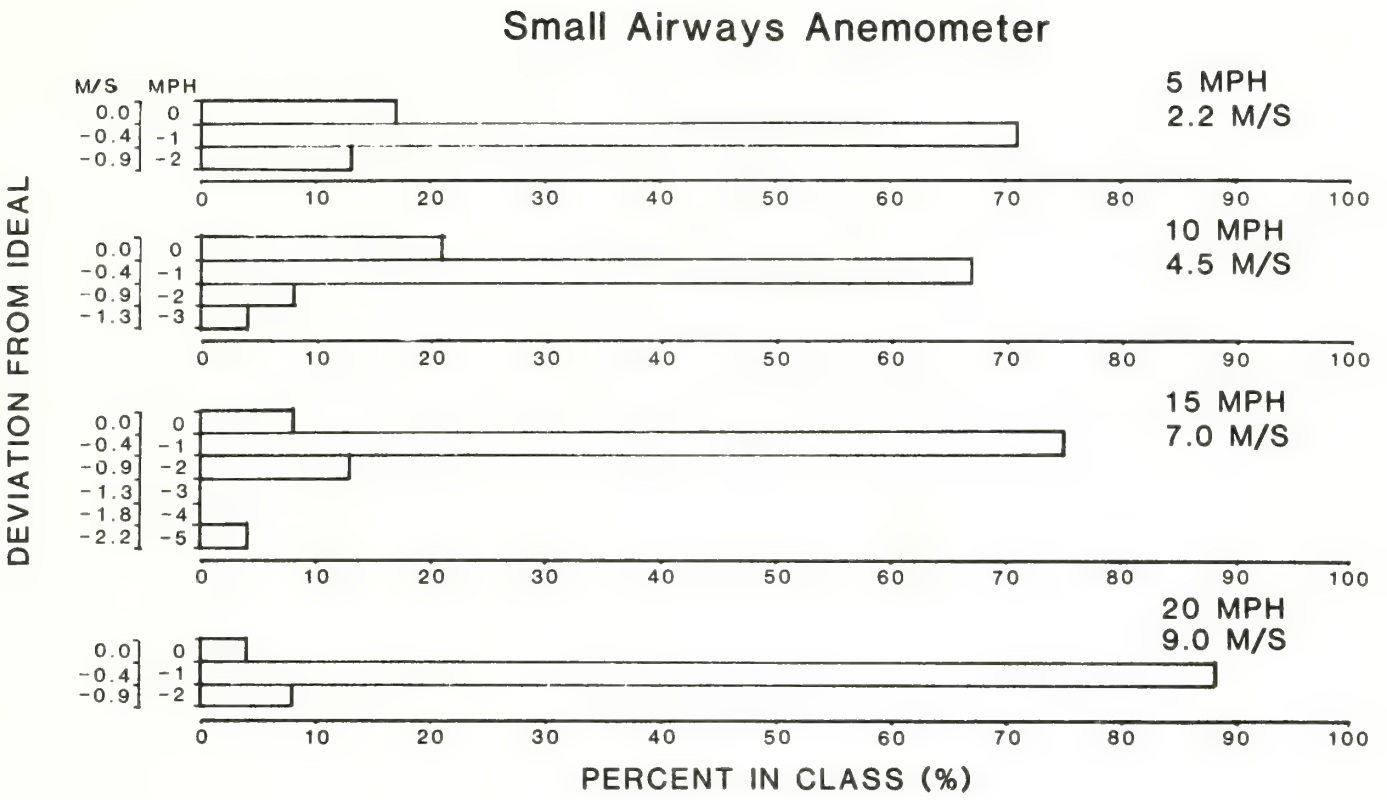


Figure 6.—*Deviations of the Small Airways anemometer from ideal at four wind speeds. Twenty-four instruments were tested.*

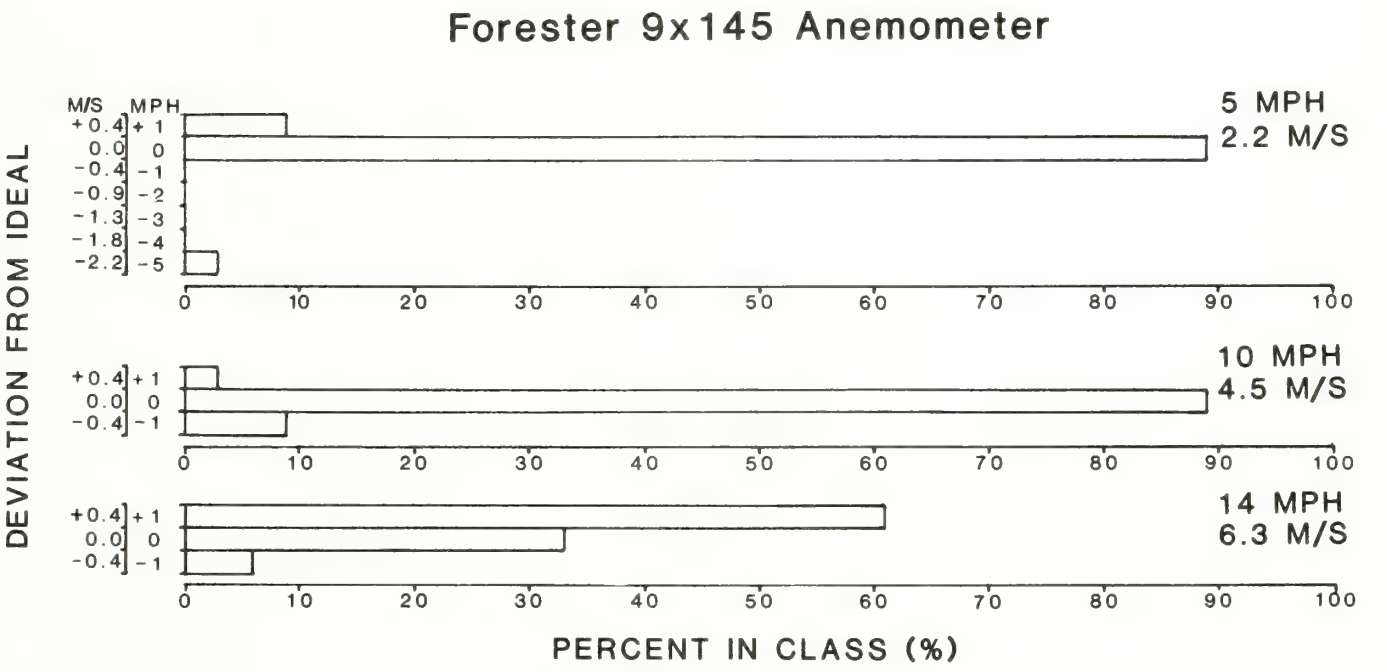


Figure 7.—*Deviations of the Forester 9 ×145 anemometer from ideal at four wind speeds. Thirty-five instruments were tested.*

Table 1.—*Wind tunnel specified corrections to be applied to individual observations to obtain ideal wind speed*

(In mph)

Ideal wind speed (mph)	Anemometer			
	Airways	Forester 9 x 145	M.C. Stewart	Natural power
5	+1.0	-0.5	+1.0	+1.0
10	+0.5	-0.5	+1.0	+1.0
15	+0.5	-0.5	+1.5	+1.0
20	+1.0	-0.5	+1.5	+1.0
25	+1.0	-0.5	+1.0	+1.0
30	+0.5	-1.0	+0.5	+1.0
35	+0.5	-1.5	±0.0	+1.0
40	+0.5	-2.0	±0.0	+1.0

Otherwise, airport forecasts will over predict wind speeds and resultant wildfire spread rates in the forest environment.

ACKNOWLEDGMENTS

We thank Gerald Gill, University of Michigan, and William Fischer, U.S. Department of Agriculture, Forest Service, for reviewing the manuscript.

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U.S. GOVERNMENT PRINTING OFFICE: 1984—565-097/10080

Haines, Donald A.; Frost, John S.
Anemometer performance at fire-weather stations. Res. Pap. NC-256. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 8 p.

A survey of 142 fire-weather stations in the Northeastern United States showed that, although maintenance was generally satisfactory, calibration or testing of anemometers was virtually nonexistent. We tested these anemometers using portable equipment that we designed and found the deviations from true wind speed.

KEY WORDS: Wildfire behavior, fire-danger rating.

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1984
PREVENT FOREST FIRES

United States Department of Agriculture

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Research Paper **NC-257**

Diameter Growth, Survival, and Volume Estimates for Trees in Indiana and Illinois

W. Brad Smith and Stephen R. Shifley

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Smith, W. Brad; Shifley, Stephen R.
Diameter growth, survival, and volume estimates for trees in Indiana and Illinois. Res. Pap. NC-257. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 10 p.

Measurements of more than 15,000 Indiana and Illinois trees were summarized by species and diameter class into tables of mean annual diameter growth, annual probability of survival, net cubic foot volume, and net board foot volume. In the absence of better forecasting techniques, this information can be utilized to project short-term changes for Indiana and Illinois trees, inventory plots, stands, or forests.

KEY WORDS: D.b.h., growth, cubic foot volume, board foot volume, crown class, mortality.

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St. Paul, Minnesota 55108
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September 1984

DIAMETER GROWTH, SURVIVAL, AND VOLUME ESTIMATES FOR TREES IN INDIANA AND ILLINOIS

W. Brad Smith, *Research Forester,*
and **Stephen R. Shifley,** *Research Forester*

ABSTRACT.—Measurements of more than 15,000 Indiana and Illinois trees were summarized by species and diameter class into tables of mean annual diameter growth, annual probability of survival, net cubic foot volume, and net board foot volume. In the absence of better forecasting techniques, this information can be utilized to project short-term changes for Indiana and Illinois trees, inventory plots, stands, or forests.

KEY WORDS: D.b.h. growth, cubic foot volume, board foot volume, crown class, mortality.

During the past three decades many permanent forest inventory plots throughout Indiana and Illinois have been established and maintained by forest managers and researchers from forest industries, universities, and the USDA Forest Service. Individually, these data sets represent many small geographic areas, but collectively they provide a comprehensive picture of average growth and mortality rates and tree volume characteristics found throughout Indiana and Illinois during the time period from 1949 to 1977. This note summarizes average annual growth and mortality rates and average net volumes observed from measurements on more than 15,000 trees from Indiana and Illinois.

Summaries by species and diameter class highlight general trends and serve to guide planners and forest managers when more detailed sources of information are unavailable.

We obtained continuous forest inventory tree growth and mortality data from the following sources:

Tract name	Location	Years of measurement	Number of plots
Indiana demonstration woodlots	Throughout Indiana	1958-1964	718
Hoosier National Forest	South-central Indiana	1966-1976	78
Bottomland hardwood study plots	Throughout Indiana	1966-1977	33
Sinissippi Forest	North-central Illinois	1943-1963	439
Kaskaskia Experimental Forest natural area	South-central Illinois	1958-1973	8

We owe special thanks to W. Lloyd Fix and W. L. Mills, Purdue University; Dieter Pelz and George Gertner, University of Illinois; Dave Stenger, Sinissippi Forest; and Richard Schlesinger, USDA Forest Service, for providing major portions of the data base. Information for tree volume estimates came from nearly 1,000 forest inventory plots that were measured when Indiana's forests were surveyed in the late 1960's (Spencer 1969).

The summary of diameter growth by species group and diameter class shows that mean annual diameter growth rates ranged from 0.05 inch (0.1 cm) per year for noncommercial species to 0.24 inch (0.6 cm) per year for cottonwood (table 1). The mean annual diameter growth rate for all trees was 0.15 inch (0.40 cm). The diameter growth rate for small shortleaf

pines is markedly greater than for hardwood trees of similar size. Shortleaf pine is generally grown in plantations, thus eliminating much of the overstory competition that often diminishes growth rates for small trees growing under natural conditions. Averaged across all species, diameter growth increased with increasing diameter, but this trend was not consistent for each species group individually. Some of the variation in the diameter growth rates both among and within species groups is due to the different number of observations and different sampling error associated with each of the mean values reported. Summaries of diameter growth by crown class, diameter class, and species group clearly show the faster growth associated with trees from dominant and codominant crown classes (table 2).

The mean annual survival rate for sampled trees was 99.1 percent (table 3). Due to the prevalence of Dutch elm disease during the remeasurement period, survival rates for elm were markedly lower than those for other species.

The volume of timber on commercial forest land is commonly reported in two ways; growing-stock volume and sawtimber volume. Both are net volumes of the central stem above a 1 foot stump in live trees of commercial species having no serious defects in quality. Growing-stock volume is measured in cubic feet on trees 5 inches d.b.h. and larger to a variable 4-inch top diameter (outside bark). The U.S. Forest Service measures volume in board feet, International ¼-inch rule, for softwoods 9 inches d.b.h. and larger to a variable 7-inch top (outside bark) and hardwoods 11 inches d.b.h. and larger to a variable 9-inch top (outside bark). Poor form, however, often lowers merchantable height below where the minimum top diameter occurs, so top diameters at merchantable height generally increase as diameter increases. For example, hardwood sawtimber trees greater than 16 inches d.b.h. consistently have top d.o.b.'s in excess of 11 inches.

Net cubic-foot and board-foot volumes by species group and diameter class were averaged from more than 13,000 individual tree observations (tables 4-6). Gross tree volumes for cubic feet and International board feet were calculated using Stone's equation[1], which is a function of observed breast height diameter, merchantable height, and top diameter outside bark. Doyle board foot volumes were computed using Wiant's (1977) equation using diameter breast height and bole length. We corrected gross volume estimates for differences in bark thickness among species, and we applied field estimates of cull volume to gross volume to arrive at net tree volume.[2]

Tables 1-3 can be used to estimate average tree-by-tree growth and survival for Indiana or Illinois inventory plots. Such projections require a tree list that itemizes species, diameter, and perhaps crown class for a representative sample of trees from the stand or stands being considered. Alternatively, total stand growth can be estimated using the stand table projection techniques described by Husch *et al.* (1972). Stand table projections require a summary of the number of trees by species and diameter class.

Although simple inventory projections can be implemented using only a pencil, some paper, and a hand calculator, they are also readily computerized. For example, Moser (1980), Harrison and Rauch (1979), and Pelz (1978) all describe computerized forest data processing programs that summarize current and projected stand and stock tables from forest inventory data. Growth estimates in those programs are usually derived from increment cores taken during the inventory or from user-supplied growth-rate tables. Tables 1-3 provide a basis for estimating growth and mortality rates when no site-specific estimates are available. Moreover, local increment core measurements can be used to adjust the growth rate tables to reflect local conditions. Such an adjustment procedure using remeasurement data is described by Smith (1983).

For any of the above projection techniques, tree and stand volume can be estimated from the tables of mean tree volume presented here. Or, if all the necessary information were available, local volume equations such as those prepared for Indiana by Smith and Weist (1982) could be used.

When using the information in tables 1-6, remember that all reported values are averages for trees responding to a great variety of forest conditions and management regimes. Some average values are based on very few observations, and the values do not account for the effects of site quality, stand density, or stand manipulation on tree growth, survival, and volume. (For example, compare these results with those reported by Schoering and Fischer (1982)). Projections for a period much longer than the 10-year span encompassed by the basic data may be of questionable reliability. These data have been merged with similar information from other Central States to formulate a system of STEMS (Belcher *et al.* 1982) diameter growth and mortality models applicable in Indiana, Illinois, and surrounding States. These computer

[1] *A description of this function can be found in the appendix of: A net volume equation for Indiana (Smith and Weist 1982).*

[2] *Tables of associated merchantable heights, and merchantable top diameters are available from the authors.*

models do account for site quality, stand density, and inter-tree competition to provide more detailed and more biologically realistic projections of tree and stand growth than are possible from the information reported here.

PRINCIPLE TREE SPECIES GROUPS FOR ILLINOIS AND INDIANA[3]

Shortleaf pine ..... *Pinus echinata*
Select white oak
- White oak ..... *Quercus alba*
- Swamp white oak ..... *Quercus bicolor*
- Bur oak ..... *Quercus macrocarpa*
- Swamp chestnut oak ..... *Quercus michauxii*
- Chinkapin oak ..... *Quercus muehlenbergii*

Other white oak
- Overcup oak ..... *Quercus lyrata*
- Chestnut oak ..... *Quercus prinus*
- Post oak ..... *Quercus stellata*

Select red oak
- Cherrybark oak .... *Quercus falcata* v. *pagodifolia*
- Northern red oak ..... *Quercus rubra*
- Shumard oak ..... *Quercus shumardii*

Other red oak
- Scarlet oak ..... *Quercus coccinea*
- Northern pin oak ..... *Quercus ellipsoidalis*
- Southern red oak ..... *Quercus falcata* v. *falcata*
- Shingle oak ..... *Quercus imbricaria*
- Blackjack oak ..... *Quercus marilandica*
- Water oak ..... *Quercus nigra*
- Pin oak ..... *Quercus palustris*
- Willow oak ..... *Quercus phellos*
- Black oak ..... *Quercus velutina*

Select hickory
- Pecan ..... *Carya illinoensis*
- Shellbark hickory ..... *Carya laciniosa*
- Shagbark hickory ..... *Carya ovata*
- Mockernut hickory ..... *Carya tomentosa*

Other hickory
- Water hickory ..... *Carya aquatica*
- Bitternut hickory ..... *Carya cordiformis*
- Pignut hickory ..... *Carya glabra*
- Black hickory ..... *Carya texana*

Basswood ..... *Tilia americana*
Beech ..... *Fagus grandifolia*
Hard maple
- Black maple ..... *Acer nigrum*
- Sugar maple ..... *Acer saccharum*

Soft maple
- Red maple ..... *Acer rubrum*
- Silver maple ..... *Acer saccharinum*

Elm
- Winged elm ..... *Ulmus alata*
- American elm ..... *Ulmus americana*
- Siberian elm ..... *Ulmus pumila*
- Slippery elm ..... *Ulmus rubra*
- Rock elm ..... *Ulmus thomasii*

White ash ..... *Fraxinus americana*
Sycamore ..... *Platanus occidentalis*
Cottonwood ..... *Populus deltoides*
Sweetgum ..... *Liquidambar styraciflua*
Blackgum and tupelo
- Blackgum ..... *Nyssa sylvatica*
- Tupelo ..... *Nyssa aquatica*

Black cherry ..... *Prunus serotina*
Black walnut ..... *Juglans nigra*
Yellow poplar ..... *Liriodendron tulipifera*
Other hardwoods
- Boxelder ..... *Acer negundo*
- Ohio buckeye ..... *Aesculus glabra*
- River birch ..... *Betula nigra*
- American chestnut ..... *Castanea dentata*
- Northern catalpa ..... *Catalpa speciosa*
- Hackberry ..... *Celtis occidentalis*
- Flowering dogwood ..... *Cornus florida*
- Black ash ..... *Fraxinus nigra*
- Green ash ..... *Fraxinus pennsylvanica*
- Blue ash ..... *Fraxinus quadrangulata*
- Honeylocust ..... *Gleditsia triacanthos*
- Butternut ..... *Juglans cinerea*
- Osage-orange ..... *Maclura pomifera*
- Red mulberry ..... *Morus rubra*
- Bigtooth aspen ..... *Populus grandidentata*
- Quaking aspen ..... *Populus tremuloides*
- Black locust ..... *Robinia pseudoacacia*
- Black willow ..... *Salix nigra*
- Sassafras ..... *Sassafras albidum*

[3] *The common and scientific names of tree species are based on: Little, Elbert L., Jr. Checklist of United States Trees (Native and Naturalized). Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service, 1979. 375 p.*

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Table 1.--Mean annual diameter growth by species group and diameter class, Indiana and Illinois[1/]

(In inches)

Species group[2/]	Number of observations	Diameter class (inches at breast height) 1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	Average all classes
Shortleaf pine	132	.198	.168	.128	.120	.139	.120	--	.082	.050	--	.109	--	--	--	--	.142
Select white oak	3,476	.052	.041	.086	.089	.105	.132	.154	.172	.183	.202	.199	.193	.215	.237	.260	.134
White oak	3,313	.055	.037	.085	.089	.106	.132	.153	.172	.182	.204	.200	.183	.207	.241	.236	.134
Bur oak	124	--	--	--	.087	.091	.115	.160	.159	.170	.200	--	.445	.273	.214	--	.130
Other white oak	249	.077	.100	.107	.115	.118	.122	.133	.140	.189	.138	.113	.082	--	--	--	.124
Chestnut oak	228	.049	.100	.112	.124	.123	.126	.136	.140	.189	.138	.113	.082	--	--	--	.128
Select red oak	1,090	.048	.036	.204	.132	.166	.178	.196	.213	.219	.249	.236	.245	.279	.259	.224	.202
N. red oak	1,090	.048	.036	.204	.132	.166	.178	.196	.213	.219	.249	.236	.245	.279	.259	.224	.202
Other red oak	2,111	.045	.117	.116	.147	.147	.165	.174	.179	.181	.196	.179	.210	.262	.242	.237	.166
Scarlet oak	229	--	--	.129	.120	.206	.168	.193	.207	.181	.194	.207	.219	.294	.235	.270	.192
Black oak	1,803	.045	.117	.112	.147	.143	.163	.169	.171	.181	.190	.175	.225	.262	.256	.214	.161
Select hickory	473	.014	.039	.089	.111	.103	.109	.115	.142	.131	.152	.116	.208	.082	--	--	.109
Shagbark hickory	435	.008	.024	.101	.123	.105	.108	.117	.146	.130	.133	.116	.208	--	--	--	.112
Other hickory	702	.023	.060	.071	.077	.099	.115	.137	.150	.145	.143	.187	.131	.053	.130	--	.116
Bitternut hickory	106	--	.126	.088	.107	.102	.134	.135	.166	.176	.125	.179	.040	--	--	--	.126
Basswood	196	--	.360	.100	.209	.181	.191	.188	.176	.189	.228	.143	.189	.217	.275	.421	.192
Beech	615	.044	.033	.081	.108	.142	.163	.146	.158	.175	.152	.157	.146	.128	.122	.102	.150
Hard maple	1,626	.047	.072	.107	.140	.152	.158	.155	.158	.166	.154	.156	.129	.162	.160	.120	.138
Soft maple	340	.123	.158	.158	.193	.189	.190	.245	.184	.227	.215	.364	.211	.303	.114	.283	.202
Red maple	126	.123	.158	.165	.214	.171	.221	.332	.201	.325	.191	.436	.136	.209	--	.283	.205
Silver maple	214	--	--	.027	.097	.193	.184	.227	.182	.188	.219	.352	.223	.350	.114	--	.200
Elm	324	.041	.144	.109	.104	.166	.160	.160	.181	.185	.172	.238	.141	.271	.110	.282	.157
American elm	130	.016	.097	.087	.099	.134	.163	.169	.171	.250	.188	.117	.100	.300	--	--	.143
Slippery elm	189	.064	.223	.159	.127	.188	.158	.154	.186	.169	.144	.272	.152	.243	.110	.282	.170
White ash	567	.054	.044	.160	.152	.146	.145	.185	.158	.201	.195	.199	.178	.141	.233	.135	.152
Sycamore	159	--	--	.194	.129	.179	.183	.213	.198	.195	.225	.188	.238	.135	.195	.161	.191
Cottonwood	479	--	--	--	--	.224	.242	.222	.224	.253	.265	.281	.259	.263	.364	.253	.240
Sweetgum	84	--	--	.400	.080	.120	.095	.116	.145	.160	.093	.180	.210	--	--	--	.125
Black cherry	142	.092	.236	.210	.103	.143	.119	.136	.123	.076	.092	--	--	--	--	--	.127
Black walnut	216	.018	.040	.087	.077	.176	.127	.125	.120	.124	.137	.180	--	--	.360	--	.132
Yellow poplar	189	.101	.145	.226	.184	.166	.228	.268	.208	.219	.202	.185	.300	.094	.201	.189	.208
Other hardwoods	648	.065	.087	.133	.177	.134	.137	.164	.161	.185	.067	.135	--	.153	.060	.221	.131
Sassafras	202	.083	.093	.115	.131	.113	.112	.155	.147	.133	.133	--	--	.200	--	--	.113
Noncommercial	188	.045	.064	.063	.096	.065	.110	--	.067	--	--	--	--	--	--	--	.052
All hardwoods	13,874	.053	.075	.120	.120	.132	.149	.166	.176	.188	.194	.194	.192	.196	.216	.210	.151

[1/] Growth rates were calculated using as many observations as were available; some rates are based upon one observation. Growth rates for each diameter class larger than 20 inches were usually computed using fewer than 2 percent of the total number of observations for a given species group.

[2/] Indented entries designate individual species within a group that have 100 or more observations. Entries for the total species group are not indented and they include data for all species in that group regardless of whether information for one or more of the individual species in the group is reported separately.

Table 2.--Mean annual diameter growth by species group, crown class, and diameter class, Indiana and Illinois

(In inches)

Species group	Crown class	Number of observations	Diameter class (inches at breast height)														Average all classes
			1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	
Select white oak	Dominant	649	--	--	.103	.136	.148	.140	.152	.157	.154	.190	.172	.157	.229	--	.266	.152
	Codominant	1,331	.180	--	.121	.112	.110	.119	.130	.142	.154	.197	.155	.277	.220	--	.118	.120
	Intermediate	441	.025	.030	.076	.066	.078	.098	.099	.118	--	--	--	--	--	--	--	.079
	Overtopped	91	.053	.050	.048	.056	.050	.057	.157	--	--	--	--	--	--	--	--	.053
Select red oak	Dominant	239	--	--	--	.080	.213	.187	.194	.216	.212	.252	.210	.167	.232	.155	.161	.208
	Codominant	263	.182	--	.231	.182	.150	.153	.162	.158	.203	.276	.271	.255	--	--	--	.166
	Intermediate	53	--	--	.142	.094	.105	.114	.214	--	--	--	--	--	--	--	--	.112
	Overtopped	13	.022	.036	--	.320	.100	.093	--	.164	--	--	--	--	--	--	--	.086
Other red oak	Dominant	535	--	--	--	.229	.186	.189	.187	.186	.207	.203	.208	.207	.259	.336	--	.191
	Codominant	751	--	.191	.154	.152	.142	.154	.166	.170	.165	.217	.160	--	--	--	--	.152
	Intermediate	146	--	.073	.081	.105	.105	.103	.104	.150	--	--	--	--	--	--	--	.102
	Overtopped	14	.045	.045	.063	.064	.045	.071	--	--	--	--	--	--	--	--	--	.051
Other hickory	Dominant	82	--	.160	.100	.134	.112	.132	.130	.156	.155	.210	.191	.127	--	.130	--	.130
	Codominant	164	--	.023	.104	.114	.091	.099	.107	.119	.155	--	--	.136	.082	--	--	.100
	Intermediate	63	--	.070	.055	.071	.056	.130	.100	.209	--	--	--	--	--	--	--	.069
	Overtopped	39	.020	.047	.079	.032	.039	.036	--	--	--	--	--	--	--	--	--	.033
Hard maple	Dominant	23	--	--	--	--	.190	.226	.180	.196	.170	--	--	.145	--	.080	.100	.179
	Codominant	70	.191	.097	.164	.165	.143	.151	.161	.154	.120	.131	.173	--	--	--	--	.150
	Intermediate	35	.182	.118	.117	.173	.112	--	.178	--	--	.127	--	--	--	--	--	.142
	Overtopped	61	.048	.079	.089	.040	--	.036	--	--	--	--	--	--	--	--	--	.058
Other hardwoods	Dominant	403	.387	.325	.214	.150	.172	.193	.190	.170	.177	.210	.189	.250	.172	.233	.203	.188
	Codominant	891	.241	.213	.169	.149	.151	.161	.200	.168	.203	.178	.266	.172	.218	.230	.261	.174
	Intermediate	268	.091	.071	.109	.141	.111	.120	.154	.158	.206	--	.259	--	--	--	--	.118
	Overtopped	186	.058	.046	.096	.093	.095	.094	.108	.049	--	--	.279	--	--	--	--	.076

Table 3.--Mean annual probability of survival by species group and diameter class, Indiana and Illinois[1/]

(In inches)

Species group	Number of observations	Diameter class (inches at breast height) 1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	Average all classes
Shortleaf pine	152	.955	.970	.994	1.000	.995	--	--	--	--	--	--	--	--	--	--	.986
Select white oak	3,595	.936	.971	.997	.994	.996	.999	1.000	.999	.999	1.000	.997	1.000	.994	--	.981	.997
Other white oak	274	.893	--	1.000	.993	.990	.996	.998	1.000	.981	--	--	--	--	--	--	.991
Select red oak	1,139	--	--	.991	.989	.989	.996	.996	.997	.998	.999	.997	1.000	--	1.000	--	.996
Other red oak	2,264	.944	.983	.997	.989	.992	.995	.996	.995	.993	.997	.989	1.000	1.000	--	--	.994
Select hickory	501	.944	.951	.980	.998	.998	1.000	.998	.996	.993	--	--	--	--	--	--	.993
Other hickory	743	.942	.980	.997	.988	.996	.998	.995	.997	.996	1.000	.983	--	--	--	--	.992
Basswood	205	--	--	--	--	.994	.989	.995	1.000	1.000	.990	--	--	--	--	--	.992
Beech	636	.992	--	--	--	1.000	1.000	1.000	.989	.992	.994	.996	.994	.990	--	.977	.995
Hard maple	1,703	.987	.995	.996	1.000	.998	.997	.995	.990	.996	.998	1.000	1.000	--	--	--	.994
Soft maple	378	.978	--	.991	.992	.987	.990	.993	.984	.995	.987	--	--	--	--	.987	.989
Elm	635	.924	--	.956	.983	.908	.896	.900	.924	.849	.861	.925	--	--	--	--	.912
White ash	627	.958	--	.989	.995	.991	.998	.995	.997	.995	1.000	1.000	--	--	--	--	.988
Sycamore	171	--	--	--	--	1.000	.987	.987	.994	.994	.987	.978	.990	--	--	--	.992
Cottonwood	484	--	--	--	--	.998	.998	.998	1.000	1.000	1.000	1.000	1.000	--	--	--	.998
Sweetgum	85	--	--	--	--	1.000	1.000	1.000	1.000	--	--	--	--	--	--	--	.998
Black cherry	167	--	--	--	.973	.977	.998	.996	--	--	--	--	--	--	--	--	.984
Black walnut	223	--	--	--	1.000	.995	1.000	1.000	.994	.991	--	--	--	--	--	--	.996
Yellow poplar	197	.970	--	1.000	.986	1.000	1.000	1.000	.996	.993	--	--	--	--	--	--	.996
Other hardwoods	776	.967	.972	.979	.988	.987	.987	.997	.986	.989	.971	--	--	--	--	--	.981
Noncommercial	240	.978	.974	.974	--	--	--	--	--	--	--	--	--	--	--	--	.978
All hardwoods	15,043	.971	.979	.989	.992	.993	.995	.995	.994	.992	.994	.993	.994	.987	.989	.981	.991

[1/] All values based upon at least 10 observations.

Table 4.--Average net merchantable volume per tree to a variable 4-inch top d.o.b.[1/] by species group and diameter class, Indiana and Illinois

(In cubic feet)

Species group	Number of observations	Diameter class (inches at breast height) 5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+
Shortleaf pine	210	2.3	5.8	10.1	17.1	25.4	--	--	--	--	--	--	--	--
Select white oak	2,012	2.4	5.4	10.6	16.7	24.1	33.1	43.6	53.3	69.6	85.4	94.2	112.8	163.5
Other white oak	518	2.7	5.7	10.7	17.0	22.6	30.9	42.4	51.2	68.7	69.0	94.5	69.6	318.8
Select red oak	909	2.8	5.9	10.9	16.6	24.1	33.6	43.3	52.8	66.6	85.7	93.6	109.7	153.1
Other red oak	1,545	2.3	5.5	10.1	16.0	23.7	31.6	42.3	55.6	70.5	84.7	98.3	126.2	174.0
Select hickory	792	2.2	5.9	10.7	16.8	24.5	33.1	46.2	62.3	72.7	93.8	121.3	--	189.0
Other hickory	850	2.4	5.7	10.5	17.7	25.3	34.3	42.4	58.2	63.1	97.9	113.3	179.2	159.3
Basswood	121	2.3	6.2	10.1	15.2	24.5	29.2	41.5	49.0	71.8	82.6	--	131.5	117.5
Beech	431	2.7	6.0	10.5	18.3	26.2	34.6	43.6	58.0	68.8	79.0	110.4	117.1	137.6
Hard maple	1,074	2.7	6.5	11.4	18.6	26.1	34.6	45.4	57.3	64.7	74.7	83.5	106.2	164.1
Soft maple	437	2.6	6.2	11.5	18.6	26.2	35.9	43.4	58.7	71.2	87.7	108.2	127.4	215.1
Elm	370	2.4	5.9	10.1	17.3	25.5	31.4	41.5	53.1	67.8	68.8	114.6	--	--
White ash	767	2.4	5.6	9.8	16.1	23.8	31.7	43.0	53.6	57.8	87.4	102.7	79.7	171.3
Sycamore	411	2.4	7.0	11.3	17.9	27.2	37.5	55.5	67.7	82.9	93.4	122.4	131.0	209.4
Cottonwood	190	1.9	6.2	10.9	18.2	27.0	38.2	47.9	57.4	76.6	91.8	101.2	124.7	203.1
Willow	69	2.2	4.8	7.6	13.9	20.2	28.5	37.3	43.3	47.6	50.5	88.1	--	--
Hackberry	87	2.5	5.2	9.8	15.6	23.7	31.3	47.3	63.4	74.5	--	107.1	163.3	170.6
Bigtooth aspen	75	2.8	6.5	11.6	19.6	27.1	37.5	58.8	73.2	82.4	--	--	--	--
River birch	42	2.7	4.7	10.0	14.6	22.9	--	36.8	50.8	37.0	--	94.9	112.3	--
Sweetgum	183	2.1	5.0	10.5	17.2	26.3	36.0	43.6	56.3	88.3	73.4	103.0	125.2	110.4
Blackgum & tupelo	66	1.7	5.1	8.5	14.1	20.7	29.7	43.2	63.8	66.8	--	137.8	--	143.9
Black cherry	201	3.1	6.9	12.1	18.9	27.2	34.3	41.9	51.7	58.1	89.1	85.9	--	--
Black walnut	298	2.9	5.9	10.5	17.0	22.9	33.6	40.0	53.4	53.1	--	--	--	--
Butternut	25	2.5	6.0	10.6	16.1	31.0	27.2	--	--	--	--	--	--	--
Yellow poplar	628	2.6	6.2	11.8	18.8	26.6	38.4	53.3	65.4	79.5	96.7	139.9	121.0	186.6
Other hardwoods	495	2.1	4.7	9.2	14.5	23.3	28.3	40.0	46.9	50.2	66.7	113.9	--	154.7
All hardwoods	12,596	2.4	5.8	10.6	17.1	24.7	33.4	44.3	56.4	69.9	85.9	101.8	118.5	175.8

[1/] Average top diameter tends to increase with increasing d.b.h. due to poor form in the upper bole of large trees.

Table 5.--Average net merchantable volume per tree to a variable 9-inch top d.o.b.[1/] by species group and diameter class, Indiana and Illinois

(In board feet)[2/]

Species group	Number of observations	Diameter class (inches at breast height) 11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+
Shortleaf pine	71	66	56	--	--	--	--	--	--	--	--
Select white oak	1,608	72	115	157	212	255	330	413	412	471	604
Other white oak	441	68	111	159	212	266	366	289	474	348	1,471
Select red oak	780	75	122	174	224	272	329	450	502	549	690
Other red oak	1,305	74	121	158	218	285	353	413	497	547	730
Select hickory	542	79	121	162	236	333	389	465	584	--	784
Other hickory	555	82	124	181	222	313	274	417	451	1,023	555
Basswood	92	76	118	154	201	227	347	399	--	748	829
Beech	372	81	124	174	211	271	330	409	568	464	609
Hard maple	719	78	124	163	220	263	325	393	389	524	675
Soft maple	300	74	116	158	191	258	283	390	444	469	776
Elm	206	79	112	143	195	286	322	209	519	--	--
White ash	481	68	112	157	224	260	304	451	523	304	714
Sycamore	340	68	114	160	269	327	360	403	621	577	1,005
Cottonwood	163	73	130	179	250	287	345	508	487	643	929
Willow	48	55	87	135	150	209	232	230	359	--	--
Hackberry	65	71	104	148	264	265	301	--	784	827	606
Bigtooth aspen	47	89	127	183	326	397	542	--	--	--	--
River birch	29	63	85	--	186	183	166	--	530	539	--
Sweetgum	120	70	111	163	207	247	460	327	471	623	520
Black gum & tupelo	46	53	98	162	223	347	377	--	600	--	829
Black cherry	125	84	127	157	184	201	335	362	255	--	--
Black walnut	195	81	112	166	236	261	226	--	--	--	--
Butternut	16	71	105	106	--	--	--	--	--	--	--
Yellow poplar	510	85	129	194	272	340	420	515	715	500	817
Other hardwoods	239	67	98	128	192	216	262	362	535	--	740
All hardwoods	9,344	75	118	163	221	279	339	423	495	535	747

[1/] Average top diameter tends to increase with increasing d.b.h. due to poor form in the upper bole of large trees.

[2/] International 1/4-inch rule.

Table 6.--Average net merchantable volume per tree to a variable 9-inch top d.o.b.[1/] by species group and diameter class, Indiana and Illinois

(In board feet)[2/]

Species group	Number of observations	Diameter class (inches at breast height) 11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+
Shortleaf pine	71	33	41	--	--	--	--	--	--	--	--
Select white oak	1,608	34	64	98	144	177	252	326	324	368	474
Other white oak	441	33	62	99	138	183	283	95	339	185	1,294
Select red oak	780	34	66	108	150	196	248	332	407	447	578
Other red oak	1,305	34	66	131	147	200	268	318	442	468	425
Select hickory	542	34	65	81	152	229	294	344	451	--	795
Other hickory	555	37	66	107	144	210	111	323	357	726	646
Basswood	92	32	61	96	137	160	241	320	--	707	709
Beech	372	32	58	90	122	174	224	264	394	310	484
Hard maple	719	32	60	90	135	175	205	283	306	419	548
Soft maple	300	31	60	93	125	179	205	264	362	398	582
Elm	206	34	58	84	103	188	235	76	406	--	--
White ash	481	31	63	97	149	179	206	361	441	353	709
Sycamore	340	28	58	86	169	220	265	278	454	434	821
Cottonwood	163	33	74	117	179	219	262	430	416	537	862
Willow	48	23	49	91	90	171	203	189	319	--	--
Hackberry	65	31	59	94	181	216	203	--	627	757	557
Bigtooth aspen	47	37	62	111	222	300	400	--	--	--	--
River birch	29	32	32	--	136	146	88	--	471	623	--
Sweetgum	120	34	63	106	132	146	340	237	476	539	204
Black gum & tupelo	46	21	56	102	152	259	231	--	518	--	767
Black cherry	125	34	63	89	126	144	268	240	252	--	--
Black walnut	195	32	55	94	156	178	172	--	--	--	--
Butternut	16	26	53	59	--	--	--	--	--	--	--
Yellow poplar	510	36	67	114	169	228	294	375	504	376	644
Other hardwoods	239	30	52	75	137	144	219	264	476	--	811
All hardwoods	9,344	33	63	102	145	193	246	313	396	428	587

[1/] Average top diameter tends to increase with increasing d.b.h. due to poor form in the upper bole of large trees.

[2/] Doyle rule.

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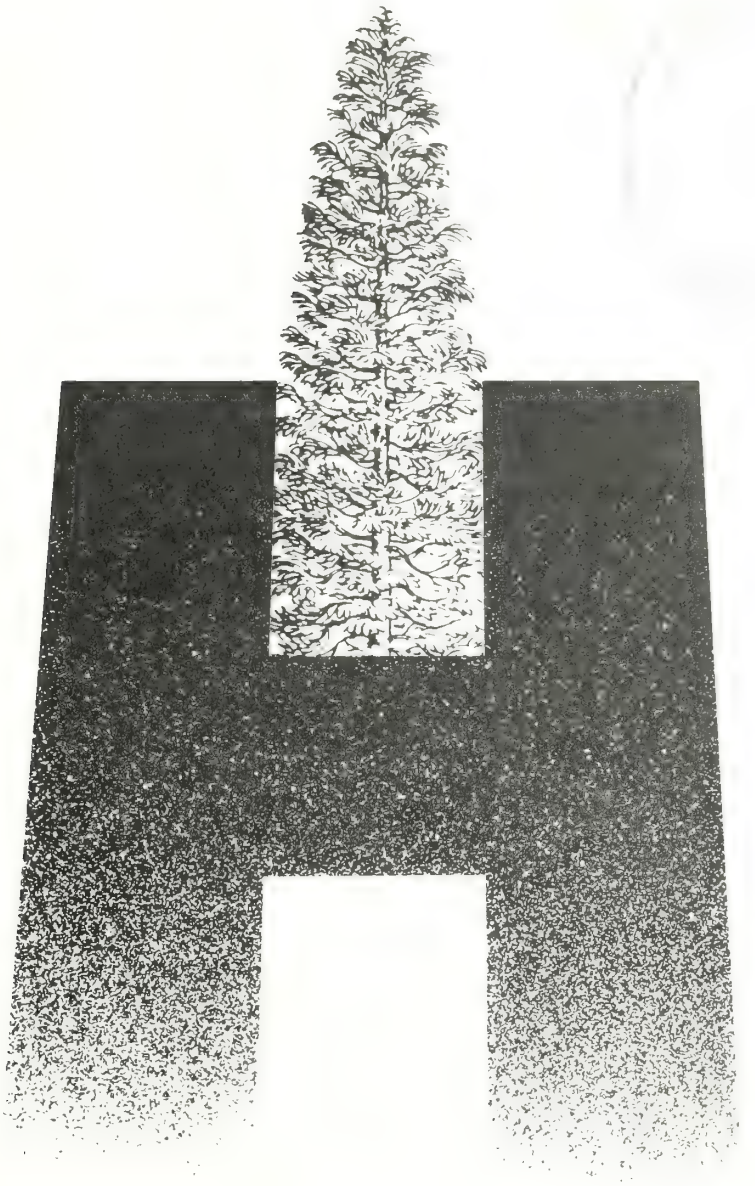
Using Glyphosate Herbicide in Converting Aspen to Conifers

Donald A. Perala



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USING GLYPHOSATE HERBICIDE IN CONVERTING ASPEN TO CONIFERS

Donald A. Perala, *Principal Silviculturist, Grand Rapids, Minnesota*

Glyphosate--N-(phosphonomethyl) glycine--is a broad-spectrum foliar active herbicide gaining international popularity for site preparation and conifer release. It is marketed by the Monsanto Company as Roundup®[1] herbicide which contains four pounds per U.S. gallon of the active ingredient, isopropylamine salt of glyphosate. Labeling for the herbicide claims good woody plant control late in the growing season, even with some fall coloration. This would be especially desirable for conifer release because most are injured by the herbicide if sprayed too early (Sutton 1978). Both conifers and competing vegetation are rate-sensitive to glyphosate (Alm 1981), but the interaction between seasonal timing and dose rates to optimize the performance of glyphosate is poorly documented.

This paper describes how glyphosate performed seasonally and at three rates mainly on quaking aspen (*Populus tremuloides* Michx.), the most common competitor of conifers on conversion sites in the Upper Great Lakes region.

METHODS

The study area is located on University of Minnesota's Cloquet Forestry Center, about 19 miles southwest of Duluth, Minnesota, in the spruce-fir forest section (Bailey 1980). The climate is humid warm-summer continental, with cold winters. July mean temperature and annual precipitation average 66°F and 27 inches. Two soil series are found on the site: Omega sandy loam (mixed, frigid Spodic Udipsamment) and Cloquet sandy loam (mixed, frigid Typic Dystrochrept). A mature stand (60 years old, site index 56) of aspen and paper birch (*Betula papyrifera* Marsh.) occupied the site. Aspen accounted for 44 percent of the total stand basal area of 83 ft² per acre. A dense shrub layer consisted mostly of hazel (*Corylus americana* Walt.) with lesser amounts of bush honeysuckle (*Diervilla lonicera* Mill.) and minor amounts of other species.

The area was clearcut (half full-tree and half tree-length logged) in the summer of 1979 and regenerated profusely to aspen suckers the next year. During late summer 1980, glyphosate was broadcast on foliage at rates of 0 (control), 1.0, 1.5, and 2.0 lbs a.i. per acre on each of four dates between August 8th and September 17th. A powered backpack sprayer was used to deliver the herbicide at a total aqueous volume of 10 gallons per acre to square plots 3000 ft² in area. Each treatment combination was replicated four times. Spraying commenced at 8:30 a.m. and was completed no later than 11:20 a.m. CST on each date. Spraying weather seemed favorable (table 1).

In late August and early September, 1981, vegetation on each plot was inventoried, summarized, and expanded to an area basis using the method of nonoverlapping triangles (Loetsch *et al.* 1973). Dominant and codominant aspen suckers (whether dead or alive) defined the corners of the triangles (five per plot). Live suckers were measured for total height (h, feet) and basal diameter (d, inches at 1 foot). Other live aspens, hardwoods, and shrubs were counted within each triangle. Herbaceous cover percent was estimated by eye on each triangle and up to three dominant species recorded. An index of biomass, $d^2 h$, was computed for

Table 1.--*Spraying weather, Cloquet, MN, 1980*

Date	Wind	Temperature		Sky	24-hr ppt[1]
		Minimum	Maximum		
	Mph	- - - - - °F - - - - -			*In*
Aug 8	10	62	80	clear	0
Aug 22	5-10	52	79	clear	0.25
Sept 2	5	50	70	clear	1.47
Sept 17	2	33	56	cloudy	0.09

[1]Rain that fell in the 24-hour period beginning at 3:00 p.m. on the spraying date. No rain fell between spraying completion and 3:00 p.m.

[1]*Mention of trade names is for the convenience of the reader and does not constitute endorsement by the USDA Forest Service over other products equally suitable.*

the dominant and codominant aspens. Total aspen d^2 h was estimated from a cumulative d^2 h/stem-number function[2]. Total aspen biomass was estimated from total d^2 h (Perala 1973).

The 2.0 lb rate of glyphosate was also applied on August 12 and 13, 1980 to another site on the Ottawa National Forest, 16 miles south-southeast of Ontonagon, Michigan. This site is in the northern hardwoods-fir forest section (Baily 1980) with climate similar to Cloquet--mean July temperature is 66°F and annual precipitation totals 32 inches. The soil series on this site is Ontonagon silty clay (mixed, Glossic Eutroboralf). A mature stand (age 47, site index 59) of quaking aspen (51 percent of total basal area) and northern hardwoods, principally sugar maple (*Acer saccharum* Marsh.) and American basswood (*Tilia americana* L.) dominated this site with 108 ft^2 of basal area. The shrub layer was relatively sparse.

This site was clearcut (whole-tree and tree-length logged) during late winter 1980 and regenerated the following summer to a dense thicket of aspen suckers and hardwood sprouts. Five acres were sprayed and five acres left unsprayed altogether on four blocks. Vegetation inventory was similar to Cloquet except that shrub and herb data were not gathered.

The data were analyzed as a randomized block design with parent aspen basal area as a covariate to remove the expected background variability in aspen suckering. Differences between the Cloquet data treatment combination means were tested for significance using Duncan's new multiple-range test (Steel and Torrie 1960).

On-site measured rainfall totaled 10.9 and 13.5 inches for the Cloquet and Ontonagon sites during June-August, 1980. This is about 7 and 24 percent above normal.

Both sites were planted with container grown (Ray Leach Pine Cells) white spruce (*Picea glauca* (Moench) Voss) in the spring of 1981. Survival was evaluated 2 years later.

RESULTS

At Cloquet, glyphosate regardless of rate significantly reduced aspen biomass and aspen and shrub stem density through September 2nd (tables 2 and 3). Results for September 17th were highly variable, ranging from significant shrub control to non-significant reduction in aspen stems. No treatment significantly controlled hardwoods. Herbaceous cover was less (but not significantly) in the treated plots than in the untreated (table 4). The frequency of grasses and sedges, large-leaved aster (*Aster macrophyllus* L.) and northern dewberry (*Rubus flagellaris* Willd.) tended to increase, and that of bracken fern (*Pteridium aquilinum* (L.) Kuhn), raspberry (*Rubus idaeus* L.), northern bead-lily (*Clintonia borealis* (Ait.) Raf.), wild sarsaparilla (*Aralia nudicaulis* L.), and strawberry (*Fragaria virginiana* Duchesne) tended to decrease on the treated plots (table 4). Overall, 1.5 or 2.0 lbs per acre of glyphosate on August 22nd were the most consistent and effective treatments in reducing aspen biomass, woody stem density, and important herbaceous competitors such as bracken fern and raspberry.

At the Ontonagon site, woody plant control was significant but not as good as at Cloquet. Aspen biomass was reduced by only 69 percent, and aspen stem count by 44 percent. Hardwood stems were 20 percent more numerous on the sprayed plots. Dominant aspen mean d^2 h was reduced by 55 percent at both sites. Survival

[2]*On file, Forestry Sciences Laboratory, Grand Rapids, MN.*

Table 2.--*Aspen biomass, as percent of unsprayed control (3,040 lbs per acre), one year after spraying glyphosate at three rates on four dates; Cloquet*

Rate (Lbs/ac., a.i.)	Date and Growing Degree-Days[1]				
	August 8 (2323)	August 22 (2638)	September 2 (2883)	September 17 (3126)	Mean[2]
	Percent of control[3]				
1.0	9^{C}	9^{C}	8^{C}	40^{bc}	8
1.5	8^{C}	3^{C}	10^{C}	15^{C}	7
2.0	5^{C}	10^{C}	9^{C}	91^{ab}	8
Mean	8	7	9	49	8

[1]Accumulated mean daily temperature exceeding 40°F.
[2]Without September 17.
[3]Values with the same letter do not differ significantly (p/gr 0.05). Value with letter "a" not significantly different from zero rate.

Table 3.--*Number of woody stems per acre one year after spraying glyphosate at three rates on four dates; Cloquet*

Rate (Lbs/ac., a.i.)	Date: August 8	August 22	September 2	September 17	Mean[1]
			ASPEN		
			Stems per acre[2]		
1.0	3,225[b]	3,070[b]	2,923[b]	10,930[ab]	3,073
1.5	2,867[b]	3,069[b]	3,822[b]	5,389[ab]	3,253
2.0	2,068[b]	3,600[b]	3,758[b]	19,288[a]	3,142
Mean	2,720	3,246	3,501	11,869	3,156
			HARDWOODS		
1.0	2,828[a]	1,049[a]	166[a]	4,629[a]	1,348
1.5	789[a]	276[a]	3,656[a]	2,234[a]	1,574
2.0	510[a]	438[a]	1,854[a]	3,278[a]	934
Mean	1,376	588	1,892	3,380	1,285
			SHRUBS		
1.0	15,916[bc]	3,714[c]	19,649[bc]	24,608[b]	13,093
1.5	7,143[bc]	6,942[bc]	4,478[c]	13,382[bc]	6,188
2.0	2,461[c]	4,676[c]	3,120[c]	12,065[bc]	3,419
Mean	8,507	5,111	9,082	16,685	7,567

[1]Without September 17.

[2]Values with the same letter do not differ significantly (p/gr 0.05). Values with letter "a" not significantly difference from zero rate (18,900, 2,440, and 40,700 stems per acre for aspen, hardwoods, and shrubs, respectively).

of container-grown white spruce after 2 years did not differ significantly by site or treatment, as seen in the following tabulation.

Site	Glyphosate	Control
	— (Percent survival) —	
Cloquet	77	82
Ontonagon	77	78

DISCUSSION AND CONCLUSIONS

Vegetation on aspen dominated sites can be controlled with glyphosate with equal effectiveness over a period of about a month beginning the second week in August, or from about 2300-2900 GDD (growing Degree Days, 40°F threshold). Aspen was not rate sensitive from 1.0 to 2.0 lbs a.i. per acre, but 1.5 to 2.0 lbs are needed to control shrubs and susceptible hardwoods such as paper birch. The higher rates are more effective probably because they better penetrate the taller aspen canopy. Glyphosate provides only temporary control of the herb community. While the apparent shift in species composition away from bracken fern and especially raspberry is advantageous to conifer survival and growth, the shift to sedges and especially grasses is disadvantageous.

Why the September 17th treatment was inferior cannot be explained. Climatic stress does not seem to be a factor although temperatures were seasonably cool--highs generally in the 50's and low 60's for the remainder of the month. Soil moisture was not inordinately limiting given the above normal summer precipitation, and frost did not occur until 25°F was recorded at the Cloquet Forestry Center on September 26th. Aspen suckers in particular had little fall coloration at least till then. It appears that control of aspen dominated sites with glyphosate after the first week or so in September might be unreliable unless limiting climatic or physiological factors can be identified.

Table 4.--*Herbaceous community summary one year after spraying glyphosate at three rates on four dates; Cloquet*

Rate		Frequency[1]	
(Lbs/ac.,a.i.)	Cover	Increasers[2]	Decreasers[3]
		Percent	
0	77	128	87
1.0	68	164	40
1.5	70	163	38
2.0	67	176	40
Date:[4]			
August 8	68	175	41
August 22	69	163	22
September 2	75	165	56
September 17	61	142	40

[1]Sum of individual frequencies.
[2]Grass and sedge, large-leaved aster, northern dewberry.
[3]Bracken, raspberry, northern bead-lily, wild sarsaparilla, strawberry
[4]Zero rate not included.

Although vegetation control at the Ontonagon site was not as good as at Cloquet, it was still sufficient to provide 3 to 4 years of relatively unrestricted conifer growth before a release is needed. Control was much more erratic at Ontonagon despite applying only one rate during an optimum spraying period. The one block that was sprayed there on August 13th was particularly poor because rain started almost immediately after spray completion (this block was not included in analysis). Glyphosate labeling cautions against such mishap and suggests that retreatment may be necessary. On the remaining blocks, control was so complete in some patches that they became dominated by fireweed (*Epilobium angustifolium* L.). In contrast, sugar maple, which is extremely difficult to control, dominated where it was abundant. That aspen was relatively poorly controlled at Ontonagon suggests intersite variability in the efficacy of glyphosate.

It is not surprising that spruce survival was unaffected by glyphosate site preparation. The herbicide is quickly inactivated in the soil and offers minimal possibility of root uptake. And 2 years is not long enough to demonstrate the effect of competition control on survival. What is unexpected, however, is the good survival on an Ontonagon soil which is notoriously difficult for seedling establishment.

ACKNOWLEDGEMENT

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use ali pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Perala, Donald A.
Using glyphosate herbicide in converting aspen to conifers. Res. Pap. NC-259. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 5 p.

Glyphosate at 1.5 to 2.0 lbs per acre active ingredient will control aspen suckers, shrubs, and herbs when applied during August to early September. There appears to be some intersite variability in the efficacy of the herbicide.

KEY WORDS: Dosage, timing, efficacy, *Populus tremuloides*, *Picea glauca*.

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Research Paper **NC-260**

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PUBLIC DOCUMENTS

Weed Control Using Herbicides in Short-rotation Intensively Cultured Poplar Plantations

Edward A. Hansen and Daniel A. Netzer

Hansen, Edward A.; Netzer, Daniel A.
Weed control using herbicides in short-rotation intensively cultured poplar plantations. Res. Pap. NC-260. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 6 p.

Summarizes a series of studies that investigated chemical weed control from time of planting to the end of the second growing season. The studies confirm the importance of weed control with preemergents at the time of planting and the importance of additional weed control before the start of the second growing season.

KEY WORDS: Competition, linuron, glyphosate, hybrid poplar.

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WEED CONTROL USING HERBICIDES IN SHORT-ROTATION INTENSIVELY CULTURED POPLAR PLANTATIONS

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Weed control is one of the most critical factors in establishing and managing short-rotation intensively cultured (SRIC) poplar plantations. During 14 years of research on SRIC plantations at Rhinelander, Wisconsin, we have investigated the importance of weed control at various stages of plantation establishment and have developed and tested methods to accomplish satisfactory weed control. Some of these results have been published (Hansen *et al.* 1984, Netzer and Noste 1978) and others have not. This paper summarizes a series of studies that investigated herbicide weed control from the time of planting through the second year of plantation growth. All the studies were on an old field site and most included fertilization and irrigation. In all studies the regular planting material was 20-cm-long unrooted hardwood cuttings. All herbicide dosages given in this paper are in kilograms active ingredient/hectare (kg/ha). The study area was located at the North Central Forest Experiment Station's Harshaw Forestry Research Farm 16 km west of Rhinelander, Wisconsin. The Research Farm has a 50-year history of potato farming. Soils are a Padus series silt loam grading to a sandy loam with a plow layer at 25 cm and a pH ranging from 6 to 7. Quackgrass (*Agropyron repens* (L.) Beauv.) is the main weed competitor; other significant weeds include yellow rocket (*Brassica* spp.), wild mustard (*Brasica kaber* (DC.) Wheeler), lamb's quarters (*chenopodium album* (L.)), white cockle (*Lychnis alba* Mill), marestail (*Conyza canadensis* (L.) Crong.), and pigweed (*Amaranthus retroflexus* (L.)).

WEED CONTROL AT PLANTING

Although poplars are usually planted in clean-tilled weed-free fields, weeds reestablish quickly. The longer that weeds can be controlled with herbicides applied at the time of planting, the larger the poplars will be and the less damage they will receive when additional weed control is needed. Preemergents applied immediately before or after planting can control weed invasion for 4 to 6 weeks or more. In our early research we asked these questions: "Does this initial weed control result in increased tree survival and growth?" and "What herbicides are most successful?" In a 1974-1976 test utilizing three replications of 16-tree plots, we investigated several herbicides and rates including combinations of pre- and postemergents (Netzer and Noste 1978). The results shown in table 1 are from the sod site (1 of 3 sites) that was disked and rototilled before planting. Preemergent linuron was consistently present in those treatments with the best survival and growth.

Further testing of preemergent herbicides in 1980-1983 on 16-tree plots with three replications confirmed that linuron was the best herbicide treatment when applied in spring before planting (table 2). Poplars on plots treated with diphenamid, alachlor, and pronamide grew better than the untreated controls. Napropamide, simazine, and linuron applied in the fall before spring planting resulted in tree growth significantly better than on the control plot that received

Table 1.--*Effect of herbicide treatments on survival and growth of 2-year-old* Populus *cuttings*[1]

Preemergent and dosage	Postemergent and dosage	Poplar	
		Survival	Height
		Percent	*Cm*
Linuron 2,	Paraquat 0.5	40	43
Linuron 2,	Paraquat 0.5[2]	38	36
Linuron 2,		33	43
Linuron 4,		25	43
Linuron 2,	Glyphosate 3,[2]	19	33
Simazine 2,	Paraquat 0.5,[2]	13	40
Simazine 1,		8	9
Simazine 2,	Glyphosate 3,[2]	4	16
Diclobenil 4,		2	8
Simazine 3,		2	6
Diclobenil 4,	Paraquat 0.5,[2]	0	0
- - - control - - -		0	0

[1]Table adapted from tables 2 and 3 in Netzer and Noste 1978.

[2]Postemergent applied in both first and second growing season 0.5,1,2,3,4, = kg of active ingredient/ha.

Table 2.--*Spring applied preemergent herbicides ranked by height of* Populus *'Tristis #1' at the end of the first growing season*

Herbicide	Rate	Tree height
	kg/ha	*cm*
Linuron	2	83[2]
Linuron	1	81
Diphenamid	6	78
Alachlor	2	69
Pronamide	2	69
Linuron/ Alachlor	2/2	65
Oxyfluorfen	0.8	63
Pronamide	1	59
Oxyfluorfen	0.3	58
Napropamide	11	55
Napropamide	13	53
Napropamide	8	52
UNSPRAYED CONTROL		48
Simazine	2	46
Napropamide/ Simazine	13/2	46
Metolachlor	3	45
Matolachlor	2	44

[1]Herbicides were applied to a new set of plots each year for 3 years (1981-1983).

[2]Treatments next to a common line are not significantly different.

no treatment (table 3). Weed competition on the control plot consisted of a dense stand made up equally of wild mustard, white cockle and lamb's quarters.

Another study during 1980-1981 (Hansen *et al.* 1984) compared herbicide treatments with cultivation and use of legume cover crops. The test consisted of a randomized block design with four replications and 6 × 40 m plots of each treatment that were large enough to allow use of common farm implements. The particular treatments tested were some of the best that had been developed over a 6-year period. Once again the treatments containing linuron ranked at or near the top in terms of tree survival:

Weed control treatment	Tree survival
	(Percent)
Glyphosate	81
Linuron-legume	76
Linuron-glyphosate	73
Linuron-cultivation	72
Cultivation	67
Legume	49
Furrow cultivation	35
Furrow cultivation-legume	18

Table 3.--*Fall-applied preemergent herbicides ranked by height of* Populus *'Tristis #1' at the end of the first growing season*

Herbicide[1]	Rate	Tree height
	kg/ha	*cm*
Napropamide	13	78[2]
Simazine	2	74
Linuron	2	73
Napropamide	11	70
Linuron/ Alachlor	2/2	70
Napropamide/ Simazine	13/2	66
Napropamide	8	61
Linuron	1	59
Oxyfluorfen	0.8	58
Diphenamid	6	50
Metolachlor	3	50
Oxadiazon	3	49
Pronamide	2	49
Metolachlor	2	42
Alachlor	2	39
UNSPRAYED CONTROL		38
Oxyfluorfen	0.3	36
Pronamide	1	35

[1]Herbicides were applied the fall before planting to a new set of plots each year for 3 years (1981-1983).

[2]Treatments next to a common line are not significantly different.

The treatments containing linuron also ranked at or near the top in terms of height growth:

Weed control treatment	Tree height
	(m)
Linuron-cultivation	3.2
Linuron-glyphosate	3.2
Cultivation	2.9
Linuron-legume	2.7
Furrow cultivation	2.7
Glyphosate	2.5
Furrow cultivation-legume	2.2
Legume	2.1

In both these tabulations, treatments next to a common line are not significantly different). These results were the same for both irrigated and unirrigated conditions.

Based on these two tests and the extensive use of linuron in routine plantation establishment elsewhere in our research program, we feel that early weed control is essential for plantation establishment, that lin-

uron is the best preemergent of those we have tested on hybrid poplars and that it is a generally safe and effective herbicide. In only 1 year out of 15 did we experience widespread linuron damage when 28 cm of precipitation in June leached linuron into the tree rooting zone.

WEED CONTROL DURING THE FIRST SUMMER

Even with linuron, weeds begin to reinvade so that within 6 weeks after planting many weeds are present. With mid-May planting, the plantations are quite heavily infested with weeds by July. We asked the questions: "Do these weeds compete with the trees?" and "Will significant growth gains occur if the weeds are removed?"

In the first preliminary test, we sprayed glyphosate 2.2 kg/ha using a tractor mounted shield sprayer on July 29, 1980 in a quackgrass infested plantation planted in May at 1 × 1 m spacing. Two 20-m wide strips were sprayed and alternate 20-m wide unsprayed strips were left as controls. Heights of 50 trees/strip were measured within 1 week of herbicide application and again at the end of the first and second growing seasons.

There was no evidence that mid-summer weed control by shielded application of glyphosate resulted in any subsequent increase in height growth (table 4). The data represent average tree height *after* excluding trees obviously damaged by glyphosate. If those trees had been included (about 16 percent), the average tree height of the sprayed strips would have been somewhat less than the unsprayed strips in all cases. We should note that this lack of tree height growth response to weed control was in a fertilized and irrigated plantation where there would be relatively little moisture or nutrient stress because of the weeds. Growth response from weed control might be obtained under less intensive cultural conditions.

Although this preliminary test indicated no effect on tree growth by control of invading weeds by shielded application of glyphosate in mid-summer, it did not clearly demonstrate that such weed control is not potentially beneficial. Damage to trees by glyphosate could have offset potential growth increases from weed control. Therefore, a second study was initiated to determine if careful weed control during the mid-portion of the first growing season results in tree growth gains and if there are some growth losses associated with the herbicides.

Table 4.--*Effect of mid-summer glyphosate spray on subsequent tree height growth*

		Tree height			Growth	
		Pretreatment	Postreatment			
	Treatment	8/6/80	9/9/80	10/6/81	1980	1981
				m		
Reg 1	(Spray	1.40	1.56	3.89	0.16	2.49
	(No Spray	1.19	1.53	3.89	0.34	2.70
Rep 2	(Spray	0.89	1.15	3.31	0.26	2.41
	(No spray	0.85	1.17	2.88	0.32	2.03

Sixteen-tree plots were selected in a newly established plantation that had a tree spacing of 1 × 1 m. These plots were selected to contain trees with uniform growth. Treatments were randomly allocated to each plot, with three replications of each treatment. Tree heights were measured at the time of the first treatment on July 6 and again in the fall after terminal budset.

Treatments were hand-hoeing, a linuron treatment, and a glyphosate treatment, plus an unweeded control plot. Hoeing was done weekly from July 6 through August 4 to a depth less than 2 cm to remove the weeds but minimize damage to the tree roots. Linuron was sprayed at 1.7 kg/ha once over both weeds and trees on July 23 using a hand-held pressurized smallplot sprayer. Glyphosate was applied at 2.2 kg/ha on August 6 with a hand-held ropewick applicator containing a 2:1 mix of water:glyphosate. The control plot received no treatment beyond the preplant linuron application of 1.7 kg/ha that the entire plantation had received. The herbicide applications were delayed for several weeks after the hoeing treatment began to allow the trees to grow larger and thereby possibly minimize damage. All treatments gave good control of weeds.

The analysis did not show any significant differences between treatments in their effect on tree height growth:

Treatment	Height growth
	(m)
Hoe	1.05
Control	1.01
Linuron	0.96
Glyphosate	0.90

The overall analysis of variance was significant only between the 0.05 and 0.10 interval. Hand-hoeing, which gave complete weed control, ranked just marginally better than the control, indicating that complete weed control during the first growing season produces little or no tree growth gains when the site has had good initial site preparation including plowing

and disking followed by a preemergent at time of planting. However, mid-summer weed control may prove beneficial on sites where soil moisture or nutrients are limiting or where weed control has been poor. Both herbicides resulted in some visual tree damage within 2 weeks of application even though extraordinary care was used in hand applying the herbicides. Although the height growth of the sprayed trees was not significantly different from that of the controls, the herbicide damage evident on the trees suggests that the marginal difference in tree growth may have been due to herbicide.

SECOND SEASON WEED CONTROL

By the end of the first growing season, weeds are once again well-established in poplar plantations. With tree spacings 3 × 3 m or greater, equipment can travel between the rows for a few more years so that weed control can be continued throughout the second growing season, if necessary. However, with tree spacings narrower than 3 × 3 m, weed control measures must be applied before second-year tree growth because the trees will rapidly reach a height where a tractor passing over the trees would damage the succulent growing tips. Also, glyphosate applied during the growing season severely damages young poplars. Therefore, we designed a test to determine if there is a time in the late fall or early spring when the actively growing weeds (primarily grasses) are susceptible to herbicide control, but the poplars are still dormant and possibly resistant to the herbicides (Danfield *et al.* 1983). The test consisted of a randomized block design with two replications and 20-tree plots with trees spaced at 1 × 1 m.

Treatments included both fall and spring herbicide applications in a 1-year-old plantation. Fall treatments in 1980 included glyphosate at 1.1 and 2.2 kg/ha; dichlobenil at 4.5 kg/ha; pronamide at 1.1 kg/ha; and hand-hoeing. Treatments were applied October 7, October 20, and November 10, 1980; glyphosate was omitted from the November 10 treatment. The earliest treatment date (October 7) was at least 1 month after bud-set and 2 to 3 weeks before the end of leaf fall. Spring treatments were glyphosate at 1.1 kg/ha; glyphosate at 2.2 kg/ha; glyphosate at 1.1 kg/ha followed 1 week later by an application of linuron at 2.2 kg/ha; and hand-hoeing. Treatments were applied April 15, April 29, May 15, June 4, and June 23, 1981. Dichlobenil at 4.4 kg/ha was applied on only the two early dates. Total tree heights were measured in September 1980 before treatment and again on August 31, 1981, at the end of the second growing season.

Herbicides applied during the dormant season between October 20 and May 15 did not significantly

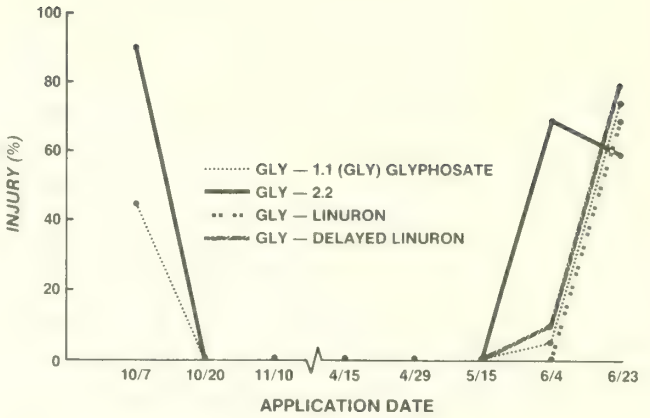

Figure 1.--*Tree injury as related to herbicide and application date.*

injure the trees (fig. 1) or reduce height growth (fig. 2). However, treatments applied earlier in the fall or later in the spring caused varying amounts of injury and reduced tree height growth depending upon the herbicide and application rate. Both dichlobenil and glyphosate controlled competition without injury to the poplars; however, the $580/ha cost of dichlobenil prohibits its use in large plantations. In contrast, glyphosate at a 1.1 kg/ha rate costs $40/ha. This test showed that glyphosate could be safely sprayed over dormant hybrid poplars between October 20 and May 15.

To further test the feasibility of dormant season spraying with glyphosate, we strip sprayed a larger plantation of a 1-year-old clonal mixture in the fall of 1981. Glyphosate was applied at 2.2 kg/ha with a tractor-mounted boom sprayer. Treatments were glyphosate overspraying on October 8 and October 28 plus an unsprayed control. No attempt was made to shield the trees, which were completely leafless. Pretreatment measurements showed an average tree height of 138 cm and 100 percent survival on all plots. Survival at the end of the second growing season (1 year after the overspray) was only 17 and 63 percent for the two clones for the October 8 spray date. However, survival was 100 percent for both the clones for the October

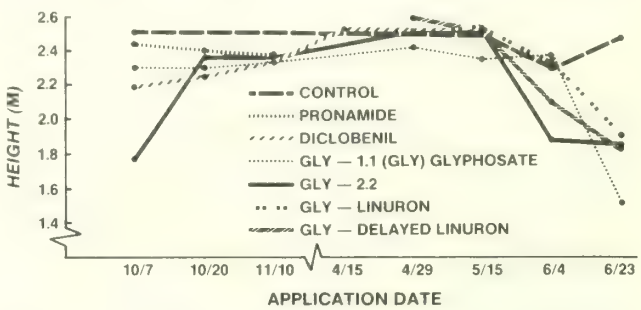

Figure 2.--*Two-year-old tree height as related to herbicide and application date.*

28 spray date and for the unsprayed control plots. Measurements showed that trees sprayed on October 28 were 16 percent taller than the unsprayed controls (18 percent greater second-year growth). In contrast, surviving trees sprayed October 8 were 35 percent shorter than the controls. This test corroborated earlier results by again showing that overspraying with glyphosate in early October damages hybrid poplars and reduces growth but that late October overspraying is safe. In addition, it showed that weed control in the fall of the first year, when done at the proper time, results in increased second-year growth.

We established a final large-scale (5-acre) trial on an old field site to test the suitability of dormant season application of glyphosate on a larger number of clones and to again measure the effects of second-year weed control on tree height growth.

The site was prepared in October 1981 by applying glyphosate at 2.2 kg/ha to control a heavy sod cover consisting mostly of quackgrass. This was followed 1 week later with moldboard plowing and disking. In spring 1982, we applied a preplant treatment of linuron at 2.2 kg/ha. Five hybrid poplar clones were planted as soaked 20-cm hardwood cuttings at 1×1 m spacing. Forbs and grasses (mostly quackgrass) began to reinvade the site in late July so that by the end of the first growing season a dense stand of quackgrass covered the site (fig. 3).

Glyphosate was oversprayed at the rate of 1.1 kg/ha to one-half of the area of each clone on May 9, 1983 (spring of the second growing season) at the time the trees were just starting to break bud (green was showing on the buds but leaves had not yet unfurled). As with all previous tests, we did not attempt to shield the trees from the herbicide. Tree growth response to weed control was dramatic (figs. 4 and 5). At the end of the second growing season, trees in the sprayed plots were 12 to 70 percent taller than trees in the unsprayed plots depending on clone (fig. 6). There was no sign of herbicide damage to any clones. This test illustrates that glyphosate may be used safely on a variety of hybrid poplar parentages when oversprayed during the dormant period and that significant second-year height growth gains result. Tests by von Althen (1981) have shown that simazine effectively controls weeds and can be safely used on poplars in the second or later years. But simazine is only marginally effective on quackgrass and will probably not work as well as glyphosate or other herbicides.

Figure 3.--*Quackgrass reinvasion in a 1-year-old hybrid poplar plantation.*

Figure 4.--*Tree height at the end of the second growing season in an unsprayed strip.*

SUMMARY

Weed control with preemergents at the time of planting has a major beneficial effect on survival and growth of hybrid poplars. In our studies, linuron applied at 1½ kg/ha at the time of planting repeatedly gave the best results of the preemergents tested.

Additional weed control in fertilized and irrigated plantations during the first summer did not increase poplar height growth in our tests. We speculate that

Figure 5.--*Tree height at the end of the second growing season in a sprayed strip.*

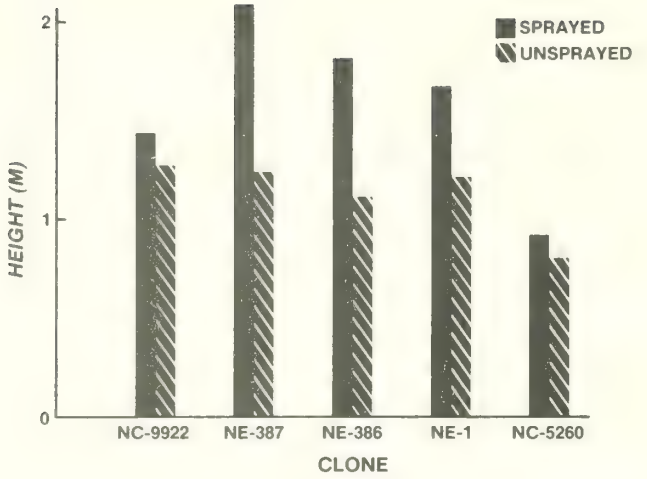

Figure 6.--*Two-year-old hybrid poplars oversprayed with glyphosate at start of second growing season.*

this was because the initial good weed control from preemergents prevented the re-establishment of dense weed cover during the remainder of the growing season. In fact, the risk of tree damage from removing the relatively few weeds during the growing season may greatly outweigh the possible small gains in tree growth. However, mid-summer weed control may prove beneficial on sites where soil moisture or nutrients are limiting or initial weed control has been poor.

Additional weed control before the start of the second growing season can be attained effectively with glyphosate and is essential for promoting rapid growth through the second growing season. Tree damage can be avoided and yet good weed control achieved in northern Wisconsin by broadcast spraying glyphosate at 1 kg/ha after October 15 or before May 15. "Safe" spray dates for other regions may vary to the extent that climate and the associated poplar phenology differ from northern Wisconsin conditions.

These studies illustrate that thorough and repeated weed control is essential to maximize growth of hybrid poplars, and they provide guidelines for achieving good weed control in poplar plantations through the second growing season.

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ENVIRONMENTAL INDICES FOR COMMON MICHIGAN TREES AND SHRUBS

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The floristic composition of a forest is the result of complicated interactions between flora and environment. To simplify this complex process, properties of an ecosystem important for sustaining plants can be grouped into four broad environmental factors: moisture, nutrients, heat, and light (Bakuzis 1959, Carleton 1982, Rowe 1956, Zedaker 1983). These factors influence the growth and survival of plants that are present despite, or because of, past natural or human-caused disturbance (Carleton 1982).

Environmental factors of a location influence how foresters manage a forest growing there (e.g. species to favor or species to plant). Ecologists also routinely report environmental factors or briefly characterize the environment (e.g. moist, cool, rich) as part of a description of forest communities. If environmental factors of a site and the corresponding requirements of forest species could be quantified, scientists and resource managers could make better descriptions and decisions. However, for several reasons, it is difficult to directly measure environmental variables and relate them to a given species' growth and survival (Daubenmire 1976, Rowe 1956, Zedaker 1983).

One possible solution is to use plants themselves as integrators and indicators of environmental factors (Bakuzis 1959, Daubenmire 1976, Rowe 1956, Zedaker 1983). This solution is not new to foresters. Site index (tree height at a standard age) integrates environmental factors to produce an indication of the potential productivity of an area.

Botanists and ecologists have frequently recorded the prevailing environmental conditions of forest species (Barnes and Wagner 1981, Fernald 1950, Gleason 1963, Rosendahl 1955). Based on these estimates and corrected by field measurements, semi-quantitative indices were determined for moisture, nutrients, heat, and light for forest species in Minnesota (Bakuzis 1959). The index for each factor is a discrete number from one to five. A value of one indicates the lowest level and five indicates the highest level for the factor. For example, a species with a moisture index of five occurs primarily in very wet environments. A species with a light index of one occurs primarily in dense shade. By calling these indices synecological coordinates, Bakuzis (1959) emphasized that they indicate environmental requirements when competing with other plants. Mean indices calculated from the individual indices of all species present provide an estimate of environmental factors of the plant community. Until more quantitative methods can be developed, species environmental indices provide a useful first approximation of their environmental requirements. The purpose of this paper is to present indices for Michigan trees and shrubs, compare them with Minnesota indices, and demonstrate how environmental indices might be used.

DETERMINING ENVIRONMENTAL INDICES

Bakuzis (1959) describes the approach for developing environmental indices. Environmental indices are first estimated from the literature and then adjusted based on field observations. Data[1] collected for the 1980 forest survey of Michigan (Raile and Smith 1983) provided the field observations. Each sample consisted of ten points uniformly spaced over an acre. At each point, trees 5.0 inches d.b.h. and larger were selected with a 37.5 factor prism. In addition, at the first three points, shrubs and small trees were sampled on fixed area subplots. Tree saplings (d.b.h. 1.0 to 4.9 inches) were recorded if they occurred within 6.8 feet of the point. Tree seedlings (d.b.h. less than 1.0 inches) and shrubs were recorded if they occurred in the northeast quadrant of the sapling subplot. Because field work occurred in every month from September 1977, to May 1981, and snow made it difficult to locate short plants, most of the the plots I selected were measured in May through October of each year. For each of the 3,943 plots selected, I recorded each species, regardless of size, that occurred.

The first step in developing environmental indices is to estimate indices as discrete numbers for each species encountered. For many species sampled in

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[1] *W. Brad Smith provided information on accessing the survey data.*

Michigan, indices had already been determined or estimated in Minnesota (Bakuzis 1959, Bakuzis and Kurmis 1978). I used them as the estimate for Michigan (table 1). Some plants were only identified by genus in Michigan. For these I used indices of a commonly occurring member of the genus. Species without Minnesota indices ("NEW" in table 1) were assigned values on the basis of range maps and ecological information (Barnes and Wagner 1981, Fernald 1950, Gleason 1963, Harlow and Harrar 1969, Rosendahl 1955, Fowells 1965). For example, white ash was assigned a light index of 3 because it was described as intermediate in tolerance (Harlow and Harrar 1969), intermediate-intolerant to intolerant (Fowells 1965), and moderately tolerant (Barnes and Wagner 1981).

The second step is to compute plot indices. The plot light index is the average of the light indices of all species present on the plot. A plot with balsam fir, sugar maple, beech, hemlock, and striped maple has a plot light index of 1.4.

The third step is to calculate average plot indices for each species. Balsam fir was present on 1,395 plots. On these plots, 2.6 was the mean plot light index. Striped maple occurred on 105 plots and the mean plot light index was 2.2.

The fourth step is to form five groups for each environmental variable. Each group consists of species with the same index for an environmental variable. Balsam fir, with a preliminary light index of 2, was grouped with striped maple and other species with a light index of 2. Because balsam fir and striped maple did not have the same index for any other variable, they were not together in another group. For each group, the average of the mean plot indices is then calculated. For example, 2.4 was the average of light group 1 and 2.6 was the average of light group 2.

The final step adjusts Minnesota values to Michigan conditions. Mean plot indices calculated in step three are compared with the appropriate values from step four. Because balsam fir had a mean plot light index closer to 2.6 than 2.4, it was assigned to light group 2 (the same as in Minnesota). Striped maple, however, had a value closer to light group 1 and was assigned a value of 1.

COMPARING MICHIGAN AND MINNESOTA INDICES

Seventy-three tree and shrub species observed on plots in Minnesota also occurred on at least 10 plots in Michigan (table 1). Most of these species (89 percent) had similar sets of indices (at least two indices with no change and the rest of the four indices within one unit of the Minnesota indices). More species in Michigan had moisture indices increase (17) than decrease (7), nutrient indices decrease (12) than increase (5), heat indices increase (7) than decrease (4)., and light indices increase (14) than decrease (10). Because Michigan tends to be warmer (Rauscher 1984) and wetter (Merz 1978) than Minnesota, heat and moisture changes may reflect an adaptation to different climatic conditions.

Nine "NEW" species and eight Minnesota species (Bakuzis and Kurmis 1978) had indices estimated only from the literature (table 1). Only 29 percent of these had similar sets of indices (compared to 89 percent for species observed in Minnesota). This indicates that there is more uncertainty in going from estimated to field adjusted indices than in going from Minnesota to Michigan indices.

Paper birch and poison ivy, occurred frequently in Michigan and Minnesota and each had an index that changed two units. The Michigan light index for paper birch was three compared with five in Minnesota. This could indicate that paper birch has a greater tolerance to shade in Michigan or that more stands with paper birch were succeeding to tolerant species. Poison ivy was not as common in Michigan as in Minnesota. In addition, there was a pronounced shift toward wetter sites in Michigan that produced an increase of two units in the moisture index.

APPLYING ENVIRONMENTAL INDICES

Ecologists routinely label plant communities with the predominant plant species. Jack pine-oak is an example. Statements about moisture, nutrient, and light conditions further describe the community. A dry, open, jack pine-oak community provides a clearer description of the community. Grigal and Ohmann (1975) used Minnesota indices (Bakuzis 1959) to provide a more quantitative description of upland communities in the Boundary Waters Canoe Area. From a list of species occurring in each community, they calculated the average value for each environmental index. The jack pine-oak community had moisture, nutrient, and light indices of 2.0, 1.8, and 3.6 respectively.

Managers can use environmental indices to help evaluate regeneration possibilities. The manager visits stands scheduled for harvesting and records tree and shrub species present as well as other factors pertinent to regenerating the stand. Environmental indices are calculated from the species list and provide additional information for selecting tree species suitable for the site. As an example, two aspen stands, each with a site index of 67, are ready for harvest. On the basis of species present in each stand, one stand has moisture/

Table 1.--*Environmental indices for moisture (M), nutrients (N), heat (H), and light (L). Values of 1 for M, N, H, and L mean dry, poor, cool, and dark, respectively. EST — Estimated by Bakuzis and Kurmis (1978), NEW — New for Michigan. Plots examined in Minnesota--356, plots examined in Michigan--3,943.*

Minnesota					Michigan					Species	
M	N	H	L	No. of plots	M	N	H	L	No. of plots		
4	2	1	2	163	4	2	1	2	1,395	Balsam fir	*Abies balsamea*
3	5	5	3	36	3	5	5	3	16	Boxelder	*Acer negundo*
3	4	4	2	EST	4	4	3	1	105	Striped maple	*Acer pensylvanicum*
2	2	3	3	70	3	2	3	3	2,575	Red maple	*Acer rubrum*
3	5	5	4	5	3	5	5	3	78	Silver maple	*Acer saccharinum*
3	5	3	1	46	3	5	3	1	1,624	Sugar maple	*Acer saccharum*
3	2	2	1	110	4	2	2	1	364	Mountain maple	*Acer spicatum*
2	1	1	4	23	3	2	2	4	17	Green alder	*Alnus crispa*
5	2	1	4	58	5	1	1	4	486	Speckled alder	*Alnus rugosa*
3	2	2	4	14	2	2	3	4	824	Juneberry	*Amelanchier* spp.
5	1	1	5	9	5	1	1	5	11	Bog rosemary	*Andromeda glaucophylla*
1	1	2	5	26	1	1	2	5	19	Bearberry	*Arctostaphylos uva-ursi*
4	5	2	2	13	4	4	2	1	830	Yellow birch	*Betula alleghaniensis*
3	2	2	5	149	3	2	2	3	1,108	Paper birch	*Betula papyrifera*
2	5	5	1	<5	2	5	5	1	131	American hornbeam	*Carpinus caroliniana*
3	5	5	1	9	2	5	5	1	70	Bitternut hickory	*Carya cordiformis*
2	3	5	4	NEW	2	5	5	2	17	Pignut hickory	*Carya glabra*
4	5	5	1	<5	2	5	5	1	62	Shagbark hickory	*Carya ovata*
5	1	1	5	19	5	1	1	5	49	Leatherleaf	*Chamaedaphne calyculata*
1	1	2	5	9	1	1	2	5	363	Sweetfern	*Comptonia peregrina*
3	4	5	1	NEW	2	5	5	2	37	Flowering dogwood	*Cornus florida*
2	3	3	2	31	2	3	3	3	274	Dogwood — dry site	*Cornus rugosa*
4	2	2	3	82	4	2	2	4	326	Dogwood — wet site	*Cornus stolonifera*
2	1	2	3	121	3	2	2	2	421	Hazel	*Corylus* spp.
3	5	4	4	8	2	5	4	4	171	Hawthorn	*Crategus* spp.
1	2	2	3	119	2	2	2	3	86	Bush honeysuckle	*Diervilla lonicera*
3	5	4	1	11	3	5	4	1	21	Leatherwood	*Dirca palustris*
3	4	4	1	EST	3	5	4	1	536	Beech	*Fagus grandifolia*
3	4	5	3	NEW	3	5	4	2	810	White ash	*Fraxinus americana*
4	3	3	2	43	4	3	2	2	662	Black ash	*Fraxinus nigra*
3	5	4	4	62	3	5	4	3	230	Green ash	*Fraxinus pennsylvanica*
2	2	3	4	EST	1	2	3	5	28	Black huckleberry	*Gaylussacia baccata*
3	4	5	2	NEW	2	3	4	4	209	Witch hazel	*Hamamelis virginiana*
4	2	3	4	<5	4	1	2	4	21	Black alder	*Ilex verticillata*
3	5	5	1	<5	3	5	5	1	12	Butternut	*Juglans cinerea*
2	5	5	2	6	2	5	5	2	16	Black walnut	*Juglans nigra*
5	1	1	5	12	5	1	1	5	11	Bog laurel	*Kalmia polifolia*
5	1	1	5	33	5	1	1	5	153	Tamarack	*Larix laricina*
5	1	1	5	54	5	1	1	5	84	Labrador tea	*Ledum groenlandicum*
4	4	4	2	NEW	3	5	5	2	28	Spice bush	*Lindera benzoin*
3	2	2	1	61	3	2	2	2	471	Honeysuckle	*Lonicera* spp.
3	3	4	3	NEW	3	4	4	4	47	Apple	*Malus* spp.
2	5	4	1	39	3	5	4	1	660	Eastern hophornbeam	*Ostrya virginiana*
3	3	4	3	50	3	4	4	3	35	Virginia creeper	*Parthenocissus quinquefolia*
3	3	3	2	<5	4	2	2	3	10	Common ninebark	*Physocarpus opulifolius*
3	2	1	2	85	4	2	1	2	581	White spruce	*Picea glauca*

(Table 1 continued on next page)

(Table 1 continued)

Minnesota					Michigan					Species	
M	N	H	L	No. of plots	M	N	H	L	No. of plots		
4	1	1	3	86	5	1	1	4	351	Black spruce	*Picea mariana*
1	1	2	5	55	1	1	2	5	353	Jack pine	*Pinus banksiana*
1	2	2	4	70	1	1	2	5	432	Red pine	*Pinus resinosa*
2	2	2	3	106	2	2	2	4	658	White pine	*Pinus strobus*
2	2	2	4	NEW	1	2	3	5	53	Scotch pine	*Pinus sylvestris*
4	3	2	3	17	4	2	2	3	365	Balsam poplar	*Populus balsamifera*
3	5	5	4	10	3	5	5	4	53	Eastern cottonwood	*Populus deltoides*
1	3	3	3	15	1	2	3	4	894	Bigtooth aspen	*Populus grandidentata*
2	2	2	4	129	3	2	2	4	1,762	Quaking aspen	*Populus tremuloides*
1	2	3	5	23	1	2	3	4	161	Pincherry	*Prunus pensylvanica*
2	3	4	3	<5	2	3	4	3	1,478	Black cherry	*Prunus serotina*
2	3	3	4	96	2	2	3	4	445	Chokecherry	*Prunus virginiana*
2	5	5	2	8	1	3	4	4	520	White oak	*Quercus alba*
4	2	4	3	NEW	3	5	5	3	41	Swamp white oak	*Quercus bicolor*
1	3	4	3	106	2	5	5	2	22	Bur oak	*Quercus macrocarpa*
1	4	3	3	70	1	3	3	4	1,192	Northern red oak	*Quercus rubra*
2	3	4	4	EST	1	3	4	5	144	Black oak	*Quercus velutina*
5	1	2	4	13	4	1	2	4	35	Alder buckthorn	*Rhamnus alnifolia*
1	3	3	4	72	3	3	3	4	124	Poison ivy	*Rhus radicans*
1	2	4	4	10	1	3	4	4	92	Sumac	*Rhus glabra, R. typhina*
4	4	2	2	120	4	3	3	2	374	Gooseberry-currant	*Ribes* spp.
3	2	5	4	EST	3	5	5	2	14	Black locust	*Robinia psuedoacacia*
1	2	3	5	39	2	2	3	5	85	Rose	*Rosa* spp.
3	2	2	3	69	3	2	3	3	1,371	Raspberry-blackberry	*Rubus* spp.
4	5	4	4	EST	4	4	4	4	42	Black willow	*Salix* nigra
4	1	2	5	<5	4	2	2	5	256	Willow shrubs	*Salix* spp.
2	5	4	1	<5	3	5	4	1	126	Elderberry	*Sambucus* spp.
3	4	4	4	NEW	1	4	5	4	140	Sassafras	*Sassafras albidum*
2	4	2	4	EST	3	2	2	4	13	Buffaloberry	*Shepherdia* spp.
2	5	4	2	34	2	5	5	3	18	Greenbriar	*Smilax* spp.
4	2	1	1	42	4	2	1	2	59	Mountain ash	*Sorbus americana*
4	3	3	3	<5	4	2	3	4	35	Spirea	*Spiraea* spp.
4	3	2	1	<5	4	3	2	1	52	Yew	*Taxus canadensis*
4	2	1	1	56	4	2	1	2	930	N. white-cedar	*Thuja occidentalis*
2	5	4	1	93	3	5	4	1	676	American basswood	*Tilia americana*
4	3	1	1	<5	4	3	2	1	588	Hemlock	*Tsuga canadensis*
3	5	4	2	79	3	5	4	1	820	American elm	*Ulmus americana*
3	5	5	3	24	3	5	5	2	95	Slippery elm	*Ulmus rubra*
2	5	5	4	EST	2	5	5	2	38	Rock elm	*Ulmus thomassii*
1	1	1	5	73	1	1	2	5	682	Blueberry — dry site	*Vaccinium angustifolium*
5	1	1	5	16	4	1	1	5	135	Cranberry — wet site	*Vaccinium oxycoccos*
3	3	3	3	16	3	3	3	3	408	Viburnum	*Viburnum* spp.
2	5	5	5	34	3	5	5	4	46	Grape	*Vitis* spp.
2	5	5	1	18	2	5	5	1	43	Prickly ash	*Zanthoxylum americanum*

nutrient indices of 3.8/2.5 and the other has 1.4/2.6. If the management objective is to convert hardwood stands to conifers and if other conditions are favorable, the high moisture index of the first stand should make it a good candidate for conversion to white spruce. The other stand with a low moisture index would more appropriately be converted to red pine.

Environmental indices can also be computed for clearcut stands using shrubs and tree seedlings present. However, because the variability of stand indices is greater when few species are recorded, estimates for clearcut stands may not be very reliable. Adding groundflora species, which are also important indicators (Bakuzis 1959, Coffman and Willis 1977, Daubenmire 1976, Rowe 1956), would reduce the variability. Groundflora species are not included in table 1, but adjusted environmental indices for Minnesota groundflora are available (Bakuzis and Kurmis 1978). Until field-adjusted indices are developed, these can serve as appropriate estimates.

CONCLUSION

For most species there was little difference between the adjusted Michigan and Minnesota moisture, nutrient, heat, and light indices. However, a few species had large differences. Field measurements are necessary for new species because estimated indices often must be adjusted. Environmental indices are a practical tool for estimating the environmental factors of moisture, nutrients, heat, and light. The assumption that, most field-adjusted indices for groundflora like those for trees and shrubs, will change little from Minnesota to Michigan needs to be verified.

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Brand, Gary J. Environmental indices for common Michigan trees and shrubs. Res. Pap. NC-261. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 5 p.

Plants are indicators of environmental factors like moisture, nutrients, heat, and light. Semi-quantitative indices for these four factors were developed for 90 Michigan trees and shrubs. The indices and a tally of species present provide a simple evaluation of the environment of a forest stand and a useful management aid.

KEY WORDS: Moisture, nutrients, heat, light, synecological coordinates.

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Research
Paper **NC-262**

The Potential for Harvesting "Puckerbrush" for Fuel

James A. Mattson and Sharon A. Winsauer

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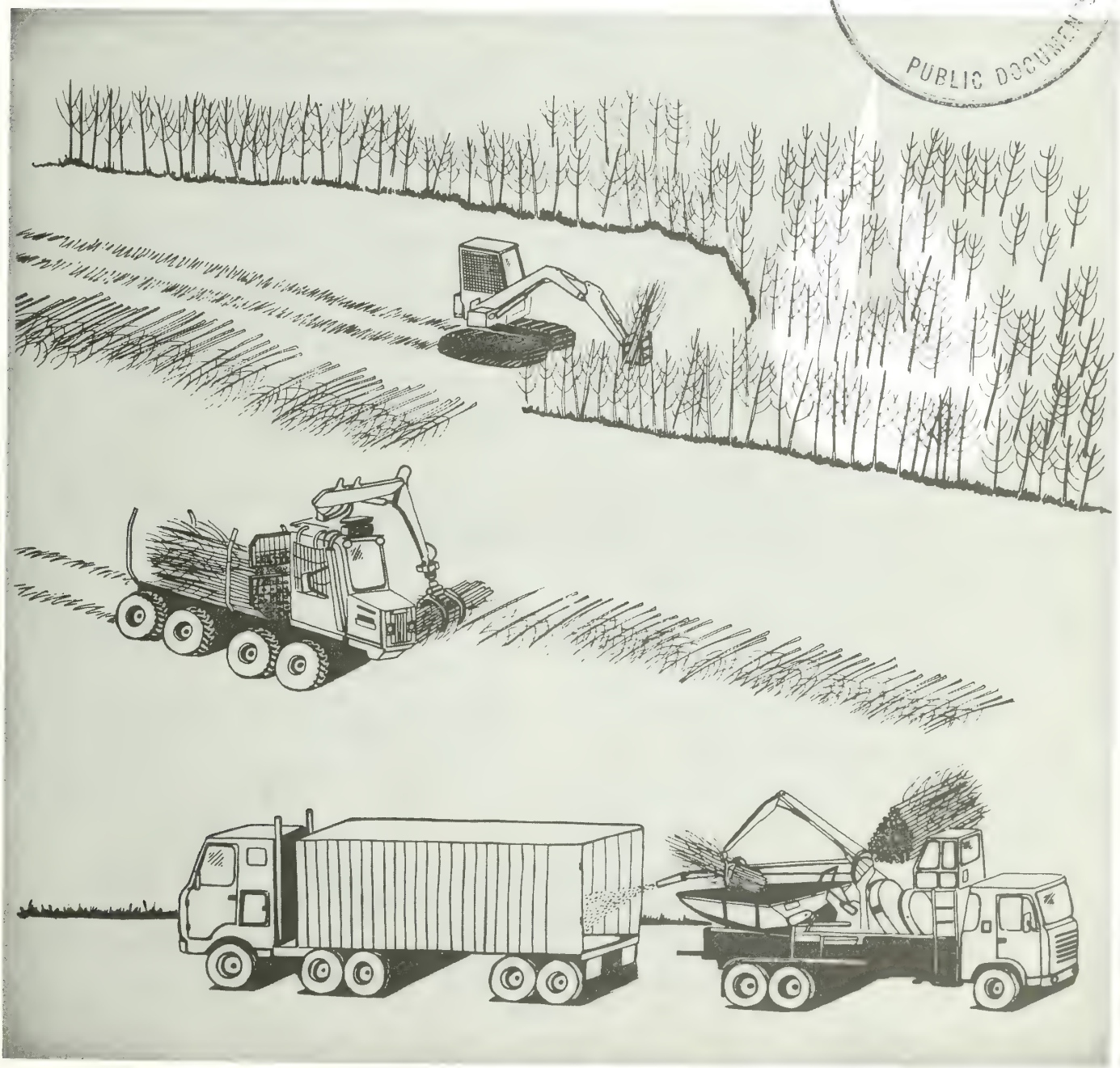

Mattson, James A.; Winsauer, Sharon A.
The potential for harvesting "puckerbush" for fuel. Res. Pap. NC-262. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 6p.

Documents the biomass in 12 typical stands of puckerbrush and evaluates the feasibility of several potential systems to harvest these stands. Identifies areas of needed development for economically viable harvesting systems.

KEY WORDS: Biomass, energy, small trees, swath harvesters, fuel drying.

North Central Forest Experiment Station
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THE POTENTIAL FOR HARVESTING "PUCKERBRUSH" FOR FUEL

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and **Sharon A. Winsauer,** *Mathemetician,*
Houghton, Michigan

Millions of acres of land in the northeastern United States are stocked with "puckerbush," a collection of small tree and brush species of no conventional commercial value (Young 1971). Puckerbrush is a rapidly growing commodity in terms of tons of biomass per acre per year. Young found that fully stocked puckerbrush stands in Maine produce more than 1 ton of dry matter per acre per year, exclusive of leaves. The rapid increases in fossil fuel prices in recent years make this material an attractive renewable energy source. Its increased value as a fuel source could also make puckerbrush worth managing on poor sites where it naturally occurs.

Utilization of puckerbrush for fuel is hampered by a lack of appropriate harvesting equipment for this type of material. The small tree sizes, large numbers of trees per acre, and poor form of the stems make it impractical to use conventional harvesting equipment. Unless suitable harvesting equipment and techniques are developed, this potentially valuable resource will go unutilized.

As the first step toward this end we conducted a study with two objectives: (1) to document the physical characteristics of those stands that have the best potential for being harvestable--that is, those stands in which the stems average more than 1 inch in diameter and that cover at least 2 acres; and (2) to evaluate the technical and economic feasibility of systems that could be used to harvest typical puckerbrush stands. Systems ranging from manual to highly mechanized and from combinations of existing equipment to the merely conceptual and not yet available may be applicable to harvesting this material. Each of these systems needs to be evaluated.

METHODS

In the Lake States region, speckled alder (*Alnus rugosa*) is a commonly occurring puckerbrush species. It frequently occurs in almost pure stands of an acre or more on both upland and lowland sites, and is the most likely candidate among the local puckerbrush species for increased utilization. This study initially concentrated on alder with the intent of later expanding into other puckerbrush species and mixed stands.

Previous studies have documented the weight of various puckerbrush species (Ribe 1973). The results of that work--regression equations relating the weight of stem, branches, and leaves to diameter at breast height (d.b.h.)--were used to estimate biomass weights on the sampled plots. This minimized weighing, greatly simplifying field work. Available data indicated that plots of 1/100 acre would be sufficient to develop reasonable estimates of the pertinent stand characteristics. Three plots per stand were taken in each of 12 stands scattered throughout the Upper Peninsula of Michigan and northern Wisconsin to obtain a regional distribution. Typical stands were identified by contacting various industrial and public agency cooperators who are familiar with the various areas.

On each 1/100-acre plot, the d.b.h. of all trees greater than 1 inch was recorded. As a check on the regression equations that were used to calculate the biomass per plot, three randomly selected trees per plot were cut, weighed, and measured for total height, d.b.h., and stump diameter. A disc was cut from the stump of each sampled tree for subsequent laboratory determination of age and moisture content.

RESULTS AND DISCUSSION

Biomass Estimates

Data from the 12 sampled stands verifies the general description of puckerbrush stands. There were many stems per acre--an average of about 5,000 stems per acre for the sampled plots--and the average stem was small. The average d.b.h. was 1.53 inches for trees greater than 1 inch. Many stems less than 1-inch d.b.h. were found on each plot, so the estimates of total biomass per plot are conservative.

Basal area ranged from 29 to 99 feet^2/acre for trees greater than 1 inch d.b.h. in the sampled stands, reflecting the range of stand densities and tree diameters. More than 80 percent of the stems were less than 2 inches d.b.h.

Stand height ranged from 12.4 to 19.9 feet, and the age was between 9 and 17 years, reflecting a preponderance of large and therefore old trees in the sample stands. Moisture content of the sampled trees was uniform and averaged 52 percent (green basis).

Total green biomass in trees larger than 1-inch d.b.h. was estimated to average 29.1 tons/acre for all the stands: 19.8 tons of stems, 5.5 tons of branches, and 3.8 tons of leaves. The biomass estimates were based on a regression equation for speckled alder (Ribe 1973). The equations used for the biomass estimates were checked against the 108 sample trees actually weighed in the sample plots to determine if there were any regional differences. Weights of the sample trees fell close to the regression estimates; therefore the estimates of biomass are expected to be reasonably accurate (fig. 1).

Trees on old field sites generally grew faster than those on forest sites, suggesting a significant site difference. Abandoned farms are likely to be better for growing puckerbrush than forest sites.

Harvesting Trial

We felt that a harvesting concept developed in Finland might be suited to selected puckerbrush stands. The technique involves manual felling with a small chain saw attached to a unique frame that allows the operator to remain upright while severing the stems (fig. 2). Experience in Finland has shown that this system makes bunching easy because the operator has only to direct the fall of the tree and not actually individually lift and pile each tree. If such a felling technique were used to fell and accumulate the small stems in a puckerbrush stand, we felt that conventional forwarding and chipping equipment could then be used to recover the trees.

An additional advantage of this system is that trees to be used for fuel could be stockpiled whole and allowed to dry before chipping. Trees stored in whole-tree form will dry to a lower moisture content than if stored in chip form, because of the easier air passage through the piles of whole trees.

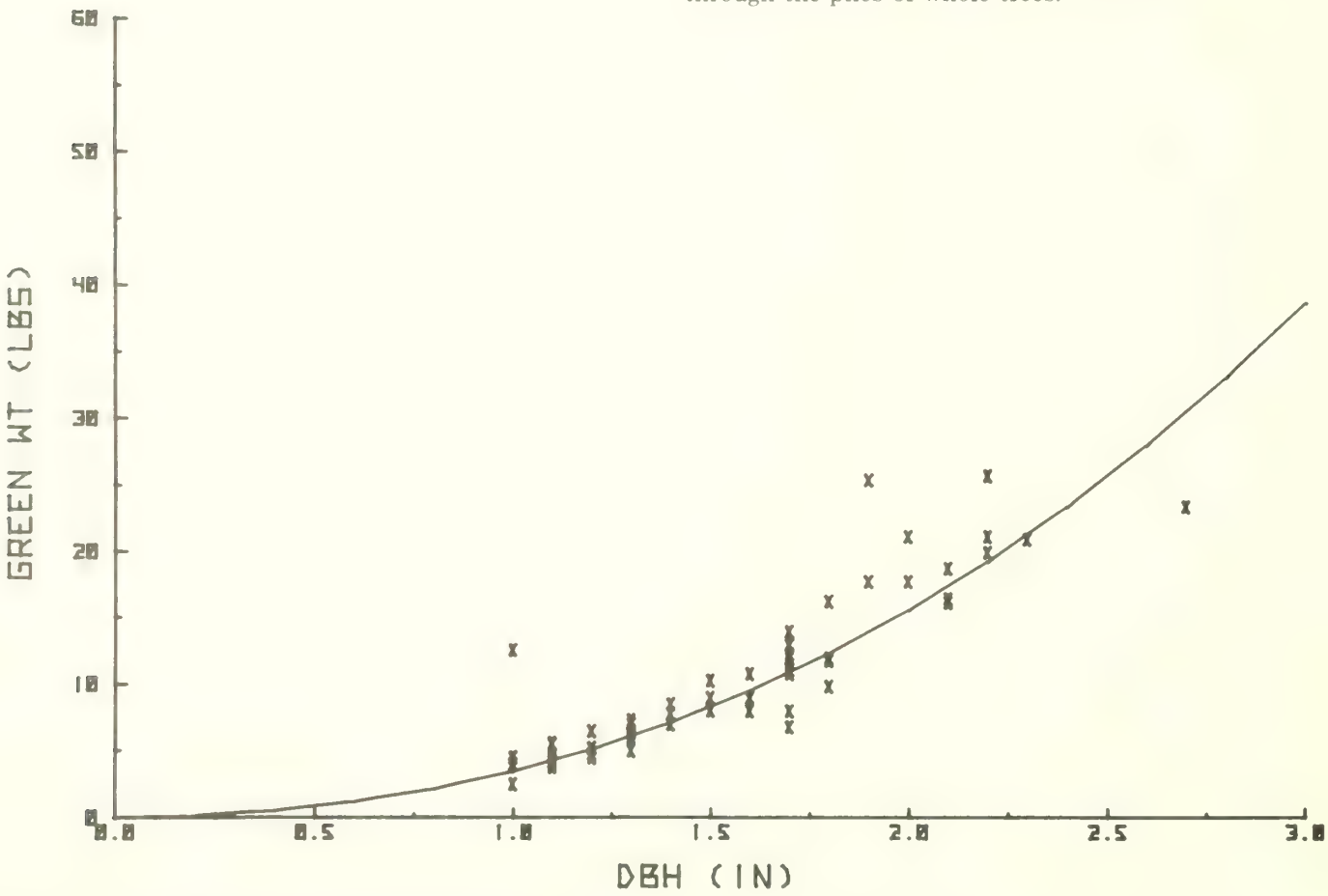

Figure 1.--*Correlation of sample tree weights to regression equation used to estimate biomass.*

Figure 2.--*Illustration of felling and accumulating small trees with the Finnish felling frame.*

We tested the technical and economic feasibility of the system in a stand located near Tomahawk, Wisconsin, where the equipment and weighing facilities of the Owen-Illinois, Inc. mill were readily available.

A commercially available felling frame suitable for mounting on a Husqvarna model 44 chain saw[1] was obtained from a manufacturer in Finland. The chain saw was equipped with a 13-inch bar for this trial. The fellers were equipped with shin protectors and safety boots designed for chain saw work.

The two individuals who did the cutting practiced for several days in another stand before starting on the test stands. A total time of 18.9 hours was spent cutting in the test stand. Forty-eight hundred stems were cut and piled in 149 bunches (table 1). Total production, 14.6 tons of greenwood, was estimated from the amount of material that was subsequently chipped. The cutting was done December 12-16, 1982, during which time only a few inches of snow was on the ground, so working conditions were good.

The material was moved to roadside with a standard Gafner Iron Mule pulpwood forwarder (fig. 3). Sixteen loads were hauled an average distance of 440 feet. The average load was 0.9 ton and 2.2 tons were hauled per productive hour. Forwarding was done on January 6, 1983. The stockpiled material was then left through

[1]*The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture to the exclusion of others which may be suitable.*

Table 1.--*Productivity for tag alder harvesting trial*

	Felling	Forwarding	Chipping
Total time (hours)	18.9	6.8	2.6
Productive time (hours)	14.8	6.5	1.6
Total stems	4,788		
Number of bunches	149		
Total loads		16	
Total green tons	14.6	14.6	
Total seasoned tons	9.7	9.7	8.2[1]
Green tons/productive hour	1.0	2.2	
Seasoned tons/productive hour	.7	1.5	5.1

[1]9.7 tons of seasoned material was calculated to be in the pile, 85 percent of which was chipped.

the following summer to dry. Four randomly selected sample trees were analyzed at the time of forwarding to obtain an original moisture content. The average moisture content of the green material was 50.8 percent (green basis).

The seasoned material was chipped on November 4, 1983, with a Morbark Super Beaver chipper (fig. 4). All told, material weighing 8.2 tons was chipped in 1.6 hours of productive time. Average moisture content was 25.6 percent on a green-weight basis. Approximately 85 percent of the stockpiled material was chipped, so the total material harvested from the plot was calculated to be 9.7 tons of seasoned wood or 14.6 tons of green wood.

Standard logging machinery cost-estimating procedures were used to estimate cost for each phases of this harvesting trial (Miyata 1980). Cost per productive hour for each phase of the operation for both the equipment and personnel is based on the percent of total scheduled time that the equipment is actually doing productive work. We estimated these to be 50 percent for the felling, 64 percent for the forwarding, and 75 percent for chipping. Combining these costs with the production rates in table 1 gives costs per green ton of $19.82 for felling, $15.80 for forwarding, and $4.07 for chipping for a total

Figure 3.--*Forwarding bunched alder to roadside.*

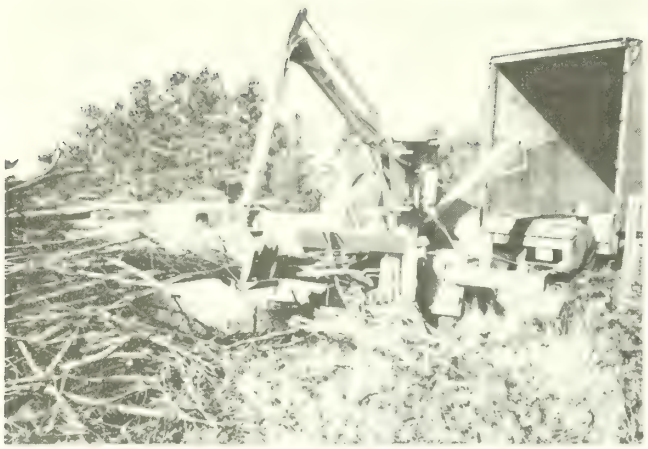

Figure 4.--*Chipping from the stockpile of seasoned alder.*

production cost of $39.69 per green ton or $57.46 per ton of seasoned wood (table 2).

The effect of seasoning becomes significant when the fuel value of the harvested biomass is considered. A total of 7.2 tons of ovendry wood was harvested. At an assumed energy content of 17 million BTU's per ton, this amounts to 122.4 million BTU's. However, it takes 2 million BTU's to remove a ton of water in the combustion process. So, considering that the green material contained 7.4 tons of water and the seasoned material 2.5 tons, the available energy content of the green wood would be reduced to less than 108 million BTU's (7.4 million per ton) and that of the seasoned material to about 117 million BTU's (12.1 million per ton) (Arola and Sturos 1981). Applying the production costs shown above then gives a total harvesting cost per million of BTU's of $5.36 for the green wood and $4.79 for the seasoned wood.

Seasoning the wood may also have other benefits. In this small study, about 5 tons of water were removed during seasoning--weight that didn't have to be transported to the use point. Dry wood is also easier to store and handle and it burns more efficiently (Riley and Drechsel 1983).

Table 2.--*Estimated cost for tag alder harvesting trial*

(In dollars)

	Felling	Forwarding	Chipping	Total
Cost per productive hour	19.82	34.76	30.52	
Production				
Green tons/hour	1.0	2.2	7.5	
Seasoned tons/ hour	.7	1.5	5.1	
Cost per ton				
Green	19.82	15.80	4.07	39.69
Seasoned	28.31	23.17	5.98	57.46

Our results show that although it is technically feasible to harvest puckerbrush with this manually intensive system, the cost is not competitive with other harvesting systems. Conventional, whole-tree chipping can deliver wood fuel for about $15 per green ton compared to $40 per green ton in this study. The major problem centers on the need to handle large numbers of very small stems. Felling and bunching accounted for about half the total production cost in this trial, primarily because it was still necessary to individually handle each small stem. A definite need exists to develop more economical, combine-type equipment that can continuously sever and collect all the stems in a swath of the stand. This would eliminate the individual handling of each stem and permit greater, most cost-effective production rates to be achieved.

Forwarding was expensive in this trial because the carrying capacity of the machine used was not fully utilized. The average load hauled was less than 1 ton. Several modifications could be made to standard forwarders that could increase the productivity and bring down this cost. A wider-opening clam on the loader would allow the operator to work on a larger bunch while still remaining within the weight limits of the loader. A smaller number of cycles to load the machine would greatly increase efficiency. Also, the load space on the forwarder could be easily increased to permit a larger volume of material to be carried on each trip without overloading the forwarder. Such modifications along with increased operator experience would bring the costs of forwarding within reasonable limits.

The chipping portion of the operation was reasonably efficient with standard equipment. The Morbark Super Beaver was able to take adequate amounts of material from the stockpile and keep the chipper operating at an efficient rate. Small changes, such as adding a funnel-shaped section in front of the chipper to help direct the stems into the feed would increase productivity. Some problem was encountered with removing the stems from the stockpile. The numerous small trees tend to tangle. This creates a problem for the chipper operator as he is trying to form a bunch for feeding into the chipper.

Working a "hot" operation, that is, chipping the material as it is being forwarded, would probably increase the productivity of the chipper. But, this would require more forwarding equipment feeding the chipper and eliminate the advantage of stockpiling the material to allow for seasoning. The material could be allowed to season at the stump, but then problems with machinery working in the stand at times other

than winter could arise. Many of the sites where puckerbrush grows are very wet and may not be workable except in winter when the ground is frozen.

Other Possibilities

Fully mechanized harvesting may be one way to solve some of these problems. Computer simulation was used to study the feasibility of mechanized harvesting techniques in puckerbrush stands. One typical stand of alder was described in greater detail to use in simulation studies. A plot of 30-foot radius was randomly located in an old-field stand, and all stems within the plot were measured for d.b.h. and plotted on a map. The map was then used to model the distribution of stems that a harvester would encounter as it worked through a typical stand. The stand consisted of 10,354 stems per acre averaging 1.22 inches d.b.h. (97.2 square feet of basal area). Green weight totaled 38.7 tons per acre; 24.3 tons of stems, 8.4 tons of branches, and 6.0 tons of leaves.

A light machine mounted on tracks might be suitable for negotiating the wet sites on which puckerbrush typically grows in the Lake States area. If such a carrier were equipped with a rotatable deck and boom, a felling and accumulating head might be developed that would cut and gather the stems as it was repeatedly swept through the stand while the machine moved intermittently forward (fig. 5). Conventional forwarding equipment could then be used to move the material to roadside for further processing or transportation.

Several combinations of boom radius and cutter head width were simulated on the computer, and the number of stems and biomass weight collected for a number of sweeps through this typical stand were

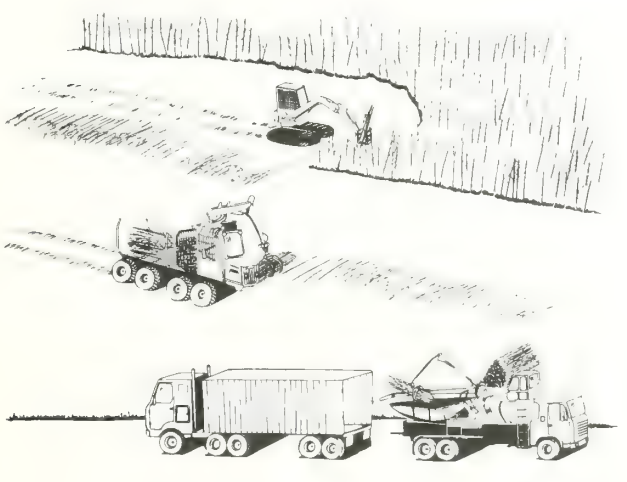

Figure 5.--*Concept of a sweeping harvester for puckerbrush.*

Table 3.--*Simulated average production rates for a swinging-type puckerbrush harvester by swing radius and width of cut*

Swing radius (feet)	Width of cut	Trees cut	Weight per cycle
	Feet	*Number*	*Pounds*
10	1	5.6	39
15	1	7.6	55
20	1	9.9	74
10	2	11.2	78
15	2	14.7	111
20	2	19.8	148

calculated (table 3). Increasing boom radius and cutter width increased the production per sweep, as would be expected. If we assume that such a machine with a 20-foot boom and 2-foot cutter could make an average of 30 sweeps per hour, the hourly production would be merely 2¼ tons per hour. Production is low because so much time is spent swinging the boom back and moving the machine forward. A more productive machine would be a swath harvester that would move continuously through the stand cutting everything in its path. If such a machine could cut an 8-foot swath through the stand at a speed of 1 mph, estimated production would be about 37 tons per hour or about 1 acre per hour.

Several prototype machines have been developed around the swath harvester concept. Koch and Nicholson (1978), Hakkila and Kalaja (1980), and Smith and O'Dair (1980) all have reported trials with swath harvesting machines designed to recover small trees and/or logging residues. The basic operational concepts of the machines have been shown to be workable, but two concerns exist about their applicability to harvesting stands of puckerbrush. So far, all such machines include chippers, adding to the horsepower required and the weight of the machine. This increased weight may preclude operating such machines in typical puckerbrush stands, such a tag alder where soil-bearing conditions are typically poor. Moreover, the machines developed to date are expensive due to their size and complexity. The cost of such equipment would require a high production rate to make them economically feasible, difficult in the small, scattered stands of puckerbrush.

CONCLUSIONS

This initial study has shown that a significant amount of biomass is available in puckerbrush stands. Twelve typical stands measured in this study averaged

about 29 green tons of biomass per acre. The high current costs of fossil fuels makes this material valuable as a fuel source. Currently available systems do not appear to be economically feasible for harvesting this material. Felling and bunching the large numbers of small stems per acre is the major problem. Initial emphasis should be put on further study of equipment and systems that can efficiently sever and collect the numerous small stems into bunches ready for forwarding from the stand. As in any wood fuel harvesting situation, the means of producing a dry fuel should also be included in the harvesting system to maximize the value of the harvested material.

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United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-263**

How to Use Hand-Held Computers to Evaluate Wood Drying

Howard N. Rosen and Darrell S. Martin

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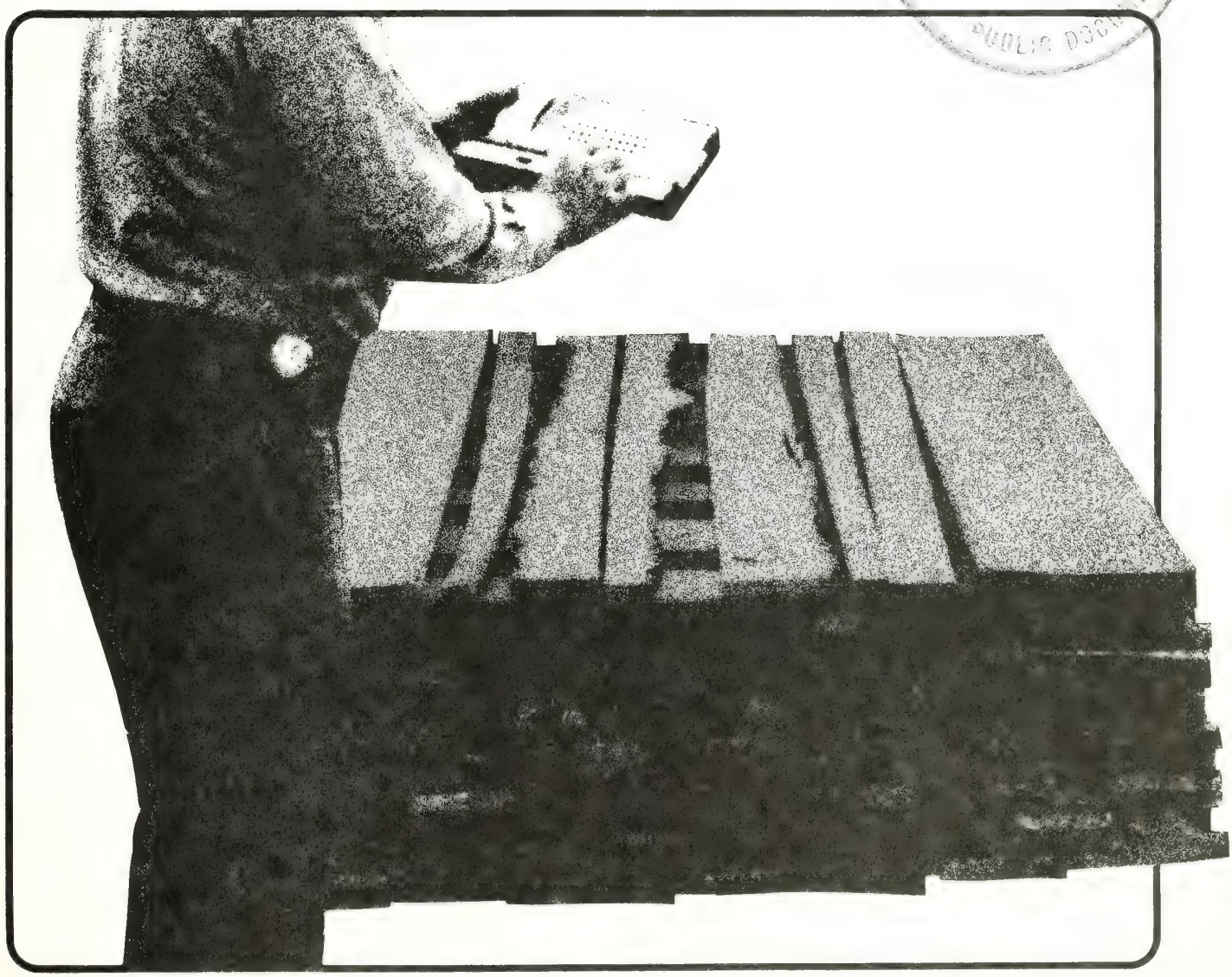

Rosen, Howard N.; Martin, Darrell S.
How to use hand-held computers to evaluate wood drying. Res. Pap. NC-263. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 17 p.

Techniques have been developed to evaluate and generate wood drying curves with hand-held computers (3-5K memory). Predictions of time to dry to a specific moisture content, drying rates, and other characteristics of wood drying curves can be made. The paper describes the development of programs and illustrates their use.

KEY WORDS: Drying rate, numerical analysis, models, psychrometric relationships, moisture content.

HOW TO USE HAND-HELD COMPUTERS TO EVALUATE WOOD DRYING

Howard N. Rosen, *Supervisory Chemical Engineer, and* **Darrell S. Martin,** *Physical Science Aid, Carbondale, Illinois*

A gap exists between the theory and practice of industrial wood processing. Wood drying is one area where sophisticated theory and mathematical models have been developed and now need to be put into practice. Hand-held computers are one way of doing it. They have the advantage over larger models of being easily portable and inexpensive, yet they are capable of sophisticated programming.

Although several companies sell hand-held computers with 1 to 8K memory (Goldfarb and Griffin 1982), few programs have been available for the wood products industry. Drying is a time-consuming and expensive step in the processing of wood. Several mathematical models have been developed recently to assist drying operators in developing schedules, evaluating final drying times, and determining basic properties of wood exposed to a particular drying environment. This paper describes several basic drying programs developed for a hand-held computer.

PROGRAMS

Five separate programs written in BASIC have been developed for a Sharp[1] PC 1500 pocket computer (weighing less than 1 lb) with a 3.5K random access memory (RAM). These programs are combined into a program package called DRYPAC (see tabulation below):

Programs Developed in DRYPAC

EMC	Determines equilibrium moisture content, humidity, or wet-bulb temperature from basic psychrometric relationships.
FIT-CURVE	Determines parameters a and b by fitting Equations (18) and (19) to a data set of three points.
FIT-CURVE-A	Determines approximate a and b when FIT-CURVE does not converge.
DRY-CURVE-1	Determines and plots a drying curve and tabulates moisture content versus time for ten time increments.
DRY-CURVE-2	Determines and plots relative moisture content versus time; tabulates these values as well as relative drying rates for ten time increments.

Programs are stored on audio cassette tapes and fed into the computer from a tape recorder. Once inside the computer memory, the program is initiated by pressing the RUN button. Only one of the five programs can occupy RAM at a given time.

Output appears on a dot graphic liquid crystal display area directly on the computer or on a four-color X-Y plotting Sharp CE-150 printer which is a separate unit. The computer, interface, and printer weight less than 3 lbs and are easily carried to any part of the wood processing plant (fig. 1).

The programs can be used on any small computer using the BASIC programming language having 3.5K RAM, but generally would have to be modified for input/output format and plotting commands. Most hand-held computers such as the Radio Shack TRS80 PC-2 or the Panasonic HHC could take a modified program.

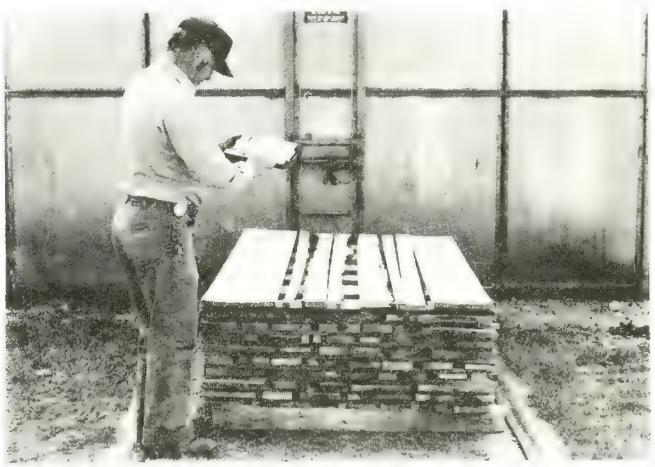

Figure 1.--*Hand-held computers can be easily carried to perform complex calculations in any part of the processing plant.*

[1]*Use of trade names does not constitute endorsement of the products by the USDA Forest Service.*

Program EMC

To evaluate a drying curve, equilibrium moisture content, EMC, must be determined from the conditions in the kiln. The EMC at atmospheric pressure is a function of dry-bulb temperature and either relative humidity or wet-bulb temperature. Also, Program EMC provides the user with EMC over a range of dry-bulb temperatures from 32 to 400°F, which is more extensive than most published tables. Program EMC calculates enthalpy and either relative humidity (RH), if wet-bulb temperature (TWB) is given, or TWB, if RH is given (fig. 1a and list 1a in Appendix B). Humidity calculations are made from basic psychometric relationships (Appendix A) (Elliott 1983).

The program will ask for dry-bulb temperature ("TDB = ?") and relative humidity "RH = ?"). If RH is not known, any negative number can be input, i.e. "−1," and the program will ask for wet-bulb temperature ("TWB = ?"). Temperatures should be input to 0.1°F and RH to 0.1 percent. The program requires less than 3 minutes to run in most situations.

Output illustrated by three separate outputs (table 1), will include the input data as well as either RH or TWB, EMC to 0.1 percent, and enthalpy to 0.1 Btu/lb dry air. If an improper RH is input to the program, the message "INVALID HUMIDITY" will be the output.

Program FIT-CURVE

If data of moisture content at various drying times are given, Program FIT-CURVE will determine two parameters, a and b (will list as A and B for clarity of copy), which describe and can be used to calculate basic properties of the curve (fig. 2a and list 2a in Appendix B). Moisture content data (initial moisture content, equilibrium moisture content, and moisture content at three selected times) must be entered into the program. The three moisture contents at selected times must be converted to relative moisture content, E, by Equation (12) and then must meet the following criteria: one at a short time (E_S, t_S) where $E > 0.90$, one when approximately half the water is removed from the wood (E_M, t_M) where $0.45 < E < 0.55$, and

Table 1.--*Sample outputs from Program EMC*

1		2		3	
GIVEN:		GIVEN:		GIVEN:	
TDB =	140.0	TDB =	215.0	TDB =	300.0
TWB =	110.0	TWB =	205.0	RH =	21.9
RESULTS:		RESULTS:		RESULTS:	
RH =	38.8	RH =	81.8	TWB =	211.5
EMC =	5.8	EMC =	10.3	EMC =	0.8
ENTHALPY =	91.3	ENTHALPY =	4754.1	ENTHALPY =	99830.2

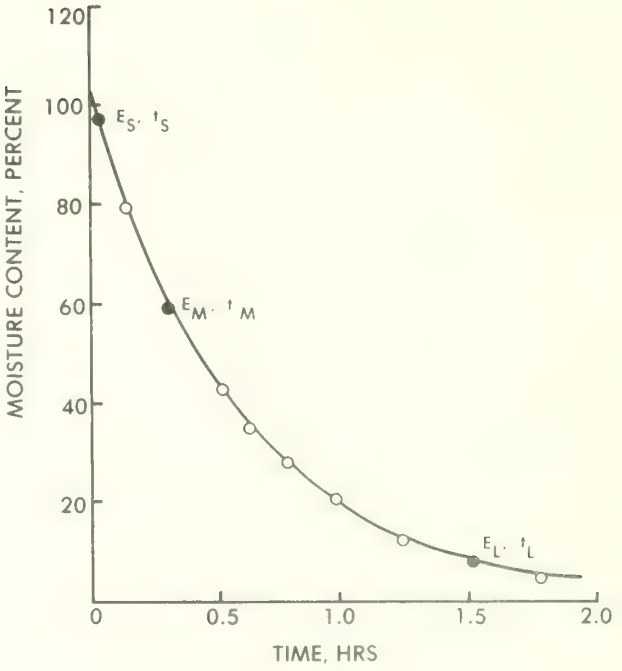

Figure 2.--*Typical drying curve and three data points required for input to Program FIT-CURVE (see Input 1 in table 2).*

one at a long time (E_L, t_L) where $E < 0.15$ (fig. 2). Also, the range of time data should be in units such that the maximum time is no greater than 100, but optimally near 10. For example, if E = 0.04 at 3000 minutes, the program will run more efficiently if the minutes were converted to 50 hours.

The program will ask for initial moisture content ("IMC ="), equilibrium moisture content ("EMC ="), and data points ("TS =", "MCS =", "TM =", "MCM =", "TL =", "MCL ="). Moisture contents should be input to 0.1 percent and times to three decimal places or less. Output consists of values for A, B, and D (criterion for fit; $D < 0.01$ is a good fit).

Sample input of data show convergence of a and b in 4 minutes with a very close fit (table 2--Input and Output 1). In many cases for highly nonlinear functions, the program will not converge. Thus, a message "TRY ALTERNATE" will be output after approximately 10 minutes as in table 2--Input and Output 2. A solution with the data of Input 2 can be approximated with Program FIT-CURVE-A.

Program FIT-CURVE-A

If the Program FIT-CURVE does not converge to value of a and b, this program will provide values (fig. 3a and list 3a in Appendix B). The program requires the same input format and will provide the same output format (except that the criterion for fit is DA rather than D) as Program FIT-CURVE. The Pro-

Table 2.--*Sample Input and Output from Program FIT-CURVE and FIT-CURVE-A*

FIT-CURVE

Input 1				Input 2			
"IMC ="	105.0,	"EMC ="	5.0	"IMC ="	74.0,	"EMC ="	4.0
"TS ="	0.04,	"MCS ="	97.3	"TS ="	0.004,	"MCS ="	70.5
"TM ="	0.30,	"MCM ="	59.0	"TM ="	0.50,	"MCM ="	43.2
"TL ="	1.50,	"MCL ="	8.5	"TL ="	4.50,	"MCL ="	8.9

Output 1		Output 2
"A =	2.036"	
"B =	0.914"	"TRY ALTERNATE"
"D =	0.002"	

FIT-CURVE-A

Input 3
(Same as Input 2)

Output 3

"A =	4.151"
"B =	3.850"
"DA =	0.049"

gram FIT-CURVE-A will not give as close a fit as FIT-CURVE and requires 10 minutes computing time but is adequate in many instances (table 2--Input and Output 3).

Program DRY-CURVE-1

This program generates a drying curve of moisture content versus time (fig. 4a and list 4a in Appendix B). The program will ask for parameter values ("A = ?", "B = ?"), initial and equilibrium moisture contents ("IMC = ?", "EMC = ?") and units of time ("TIME UNITS = ?"). Units of time must fill four spaces, such as DAYS, HRS., MIN., SEC., etc. Output consists of a drying curve in moisture content (MC) in percent versus time (T), a table of the same information with data to two decimal places, and a listing of A, B, and EMC (fig. 3). The program provides results in 3 to 5 minutes depending on the values of the parameters.

Program DRY-CURVE-2

This program is similar to DRY-CURVE-1, only the program is intended for more basic work (fig. 5a and list 5a in Appendix B). Input requires only parameter values ("A = ?", "B = ?"). Output provides a plot of relative moisture content, E versus drying time, a table of dry time (T), E, and relative drying rate (RDR) in scientific rotation to three significant digits calculated from Equation (13) (fig. 4). Researchers should find this program useful to determine initial drying rates and characteristic drying curves.

General

DRYPAC is most applicable when drying is being done at constant conditions of temperature and humidity, so that EMC is constant during the entire drying time. Constant conditions are not normally maintained in commercial drying operations. In many cases, drying curves for varying conditions can be fit with the analysis of DRYPAC by assuming EMC is equal to that at the final drying conditions.

SUMMARY AND OUTLOOK

The program package DRYPAC can be helpful to wood processors and researchers in fitting drying data, predicting drying times, and evaluating basic parameters for efficient kiln operation. The programs are readily adaptable to hand-held computers and can be saved on cassette tape.

The development of DRYPAC allows for expansion and alteration as computer technology advances. Two possible programs to add are an economic analysis program and a program to predict drying times based on wood characteristics and kiln conditions. Microcomputer hardware technology is progressing at such a rapid pace that details of the programs might be

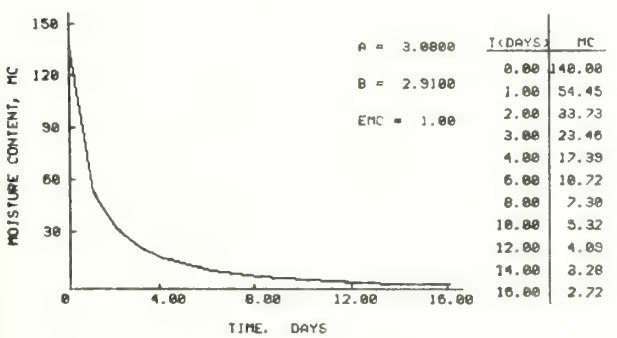

Figure 3.--*Example output of moisture content versus time plot and tabular values from Program DRY-CURVE-1.*

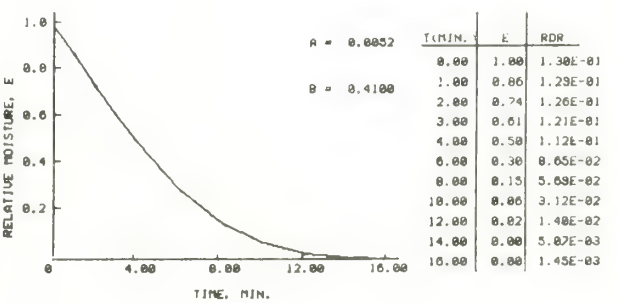

Figure 4.--*Example output of relative moisture content versus time plot and tabular values from Program DRY-CURVE-2.*

done more efficiently in the near future. For example, hand-held computers now have 16K RAM plug-in units which could store the entire DRYPAC package. The wood industry must be alert to the expanding microcomputer technology and use this technology to produce the best quality wood product in the most efficient manner.

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APPENDIX A

a	rate factor, hr^b
b	bend factor
D	difference defined by Eq. (22)
DA	difference defined by Eq. (23)
E	relative moisture content
$\dot{E}$	drying rate, hr^{-1}
h	relative vapor pressure
H	enthalpy, Btu/lb dry air
p	vapor pressure of water, psi
RH	relative humidity, percent
t	time, hr
T	temperature, °F
X	moisture content, lb water/lb dry wood
Y	absolute humidity, lb water/lb dry air
α's	constants in Eq. (2)
Γ(b)	gamma function, $\Gamma(b) = \int_0^\infty s^{b-1} \exp(-s)ds$
σ	parameter defined by Eq. (17)

Subscripts

db	dry bulb
e	equilibrium
f	final
i	initial
L	long time
M	middle time
s	saturation
S	short time
wb	wet bulb

THEORY

Program EMC

The equilibrium moisture content, X_e, must be determined from relative humidity, RH, and dry-bulb temperature, T_{db} (Simpson and Rosen 1981)

$$h = 0.01\ RH \tag{1}$$

$$X_e = \left[\frac{\alpha_1\alpha_2 h}{1 + \alpha_1\alpha_2 h} + \frac{\alpha_2 h}{1 - \alpha_2 h}\right]\frac{1800}{\alpha_3} \tag{2}$$

where:

$\alpha_1 = 3.730 + 0.03642T_{db} - 0.000154T_{db}^2$
$\alpha_2 = 0.6740 + 0.001053T_{db} - 0.000001714T_{db}^2$
$\alpha_3 = 216.9 + 0.01961T_{db} + 0.005720T_{db}^2$

Relative humidity can be determined from wet- and dry-bulb temperatures using the following psychrometric relationships (Elliot 1983):

$$Y = \frac{(1093 - 0.556T_{wb})Y_{s,wb} - 0.240(T_{db} - T_{wb})}{1093 + 0.444T_{db} - T_{wb}} \tag{3}$$

Also,

$$Y_s = \frac{0.622\ p_s}{14.7 - p_s} \tag{4}$$

$p_s = 0.000145 \exp [-5800/T' + 1.391 - 0.04864\ T' + 0.4176 \times 10^{-4}\ T'^2 - 0.1445 \times 10^{-7}\ T'^3 + 6.546\ \ln(T')]$ is the saturation vapor pressure of water (5)

and

$T' = \frac{T + 459.6}{1.8}$ is a conversion factor. (6)

Absolute humidity can then be determined by evaluating Equations (4) and (5) at the wet-bulb temperature and plugging in the value of $Y_{s,wb}$ into Equation

(3). Further

$$p = \frac{14.7Y}{0.622 + Y} \quad (7)$$

Knowing p, $p_{s,db}$ can be evaluated from Equation (5) to obtain:

$$RH = 100(p/p_{s,db}) \quad (8)$$

Enthalpy, H, in Btu/lb dry air can be evaluated from the following relationship:

$$H = 0.240(1 + 8.33 \times 10^{-6}T_{db})T_{db} + Y[1061 + 0.444(1 + 4.464 \times 10^{-6}\ T_{db})T_{db}] \quad (9)$$

The program is straightforward when T_{db} and T_{wb} are given. Equation (3) is evaluated for absolute humidity, Y, which can then be substituted into Equation (7) to determine the vapor pressure of water in the humid air. The saturation vapor pressure of water at the dry-bulb temperature, $p_{s,db}$, can be obtained from Equation (5) and, thus, relative humidity calculated from Equation (8).

When RH is given, a programmed iterative Newton method solves Equation (3) for T_{wb}. The mathematics are similar to the solution when T_{wb} is given. In this case, $Y_{s,wb}$ in Equation (3) is a complex function of T_{wb} and is unknown. Thus, a numerical technique is required to solve for T_{wb}. This iterative procedure becomes unstable near a T_{wb} of 212°F; thus, several safeguards are placed in the program to ensure a reasonable value of T_{wb} as T_{wb} approaches 212°F. If T_{wb} is determined to be greater than 211.5°F, the value is set at 211.5°F for calculations of enthalpy. For most practical kiln operations, conditions will not go above 211.5°F T_{wb}. The program also ensures that a proper RH is input; e.g. that RH cannot go above 22 percent at 300°F T_{db} and atmospheric pressure. Enthalpy is calculated from Equation (9).

Program FIT-CURVE

Drying curves for wood products are defined in terms of a rate factor, a, and bend factor, b (Rosen 1980, 1982):

Drying curve

$$E = 1 - \dot{E}_i \int_0^t \exp(-at^{1/b})dt \quad (10)$$

where

$$\dot{E}_i = \frac{a^b}{b\Gamma(b)} \quad (11)$$

$$E = \frac{X - X_e}{X_i - X_e} \quad (12)$$

Relitive drying rate

$$-\frac{dE}{dt} = \dot{E} = \dot{E}_i \exp(-at^{1/b}) \quad (13)$$

The series solution to Equation (10) is:

$$E = 1 - \dot{E}_i t \sum_{n=0}^{\infty} \frac{(-1)^n a^n t^{n/b}}{(n/b + 1)n!} \quad (14)$$

An approximate solution to Equation (10) is:

$$E = 1 - \frac{\sigma^b}{b\Gamma(b)}\left(1 - \frac{b\sigma}{b + 1}\right);\ \sigma \leq 0.5 \quad \text{(short times)} \quad (15)$$

$$E = \frac{\sigma^{b-2}\exp(-\sigma)(\sigma + b - 1)}{\Gamma(b)};\ \sigma \geq 2.0 \quad \text{(long times)} \quad (16)$$

where

$$\sigma = at^{1/b} \quad (17)$$

The program substitutes input values of E_S, t_S and E_L, t_L into Equations (15) and (16).

$$E_S = 1 - \frac{a^b t_s}{b\Gamma(b)}\left(1 - \frac{bat_S^{1/b}}{b + 1}\right) \quad (18)$$

$$E_L = (at_L^{1/b})^{b-2} \exp(-at_L^{1/b})(at_L^{1/b} + b - 1)/\Gamma(b) \quad (19)$$

Equations (18) and (19) are solved for a and b by a two-dimensional Newton-Raphson Method (Stark 1970). The gamma function of b is solved by a series expansion (Davis 1963).

Initial values of a and b must be carefully selected because of instabilities in the Newton-Raphson Method with these highly nonlinear functions. Also, Equations (18) and (19) can converge to two sets of answers depending on the initial guess of a and b--one set with $b < 1.0$ and one set with $b \geq 1.0$. Techniques have been developed to generate good initial guesses for a and b and to have a method for picking the best final values for a given set of data.

The value of b is the most critical since this value determines the degree of nonlinearity of Equation (10). From past experience (Rosen 1982), values of b fall in the range of 0.2 to 4.0. Thus, the numerical solution uses a stepwise searching technique starting with a value of b = 0.15 and incrementing b by selected amounts until a solution is found or until b = 4.0. Once each b is given, a is estimated from Equation (11):

$$\dot{E}_i = \text{initial slope of drying curve} = \frac{1.0 - E_S}{t_S} \quad (20)$$

$$a = [(\frac{1.0 - E_S}{t_S})b\Gamma(b)]^{1/b} \quad (21)$$

When two solutions are found for Equations (18) and (19), a comparision is made to determine the best solution of the two. Values of E_M and t_M from the data and those calculated by Equation (14) are substituted into the following equation:

$$D = \sqrt{(\Delta E_M^2 + 2\Delta E_L^2)/3} \quad (22)$$

where $\Delta E_M = E_M$ (calculated) $- E_M$ (data)
$\Delta E_L = E_L$ (calculated) $- E_L$ (data)

Equation (22) gives added numerical emphasis to the end of the drying, where small absolute differences in E can make a bigger difference in t than in earlier drying stages. The values of a and b corresponding to the lowest value of D are the optimal values.

Program FIT-CURVE-A

The program is similar to FIT-CURVE, but uses a direct calculation rather than the Newton-Raphson Method. The function DA is minimized over a range of b's from 0.05 to 4.1; where this range is divided into 24 increments of increasing size as the value of b increases. Greater numerical emphases on Δ E's are given on the middle and end of drying.

$$DA = \sqrt{(0.5\ \Delta E_S^2 + \Delta E_M^2 + 2\Delta E_L^2)/3.5} \quad (23)$$

where $\Delta E_S = E_S$ (calculated) $- E_S$ (data)

Program DRY CURVE-1

The program uses values of a, b, X_i, and X_e to generate a drying curve. The program must first estimate the final time to dry slightly above X_e so that the time axis of the graph can be determined.

$$t_f = (\frac{1.5 + 2b}{a})^b \quad (24)$$

Final time is then divided into ten increments, such that the four increments are closer together than the remaining six. E's are calculated for each t by Equation (14) and transformed to moisture content by Equation (12).

Program DRY-CURVE-2

Only drying parameters a and b need to generate the drying curve of E versus t by Equation (14).

Relative drying rates, $\dot{E}$, are also calculated at each t by Equation (13).

APPENDIX B — LOGIC DIAGRAMS AND LISTING OF PROGRAMS IN DRYPAC

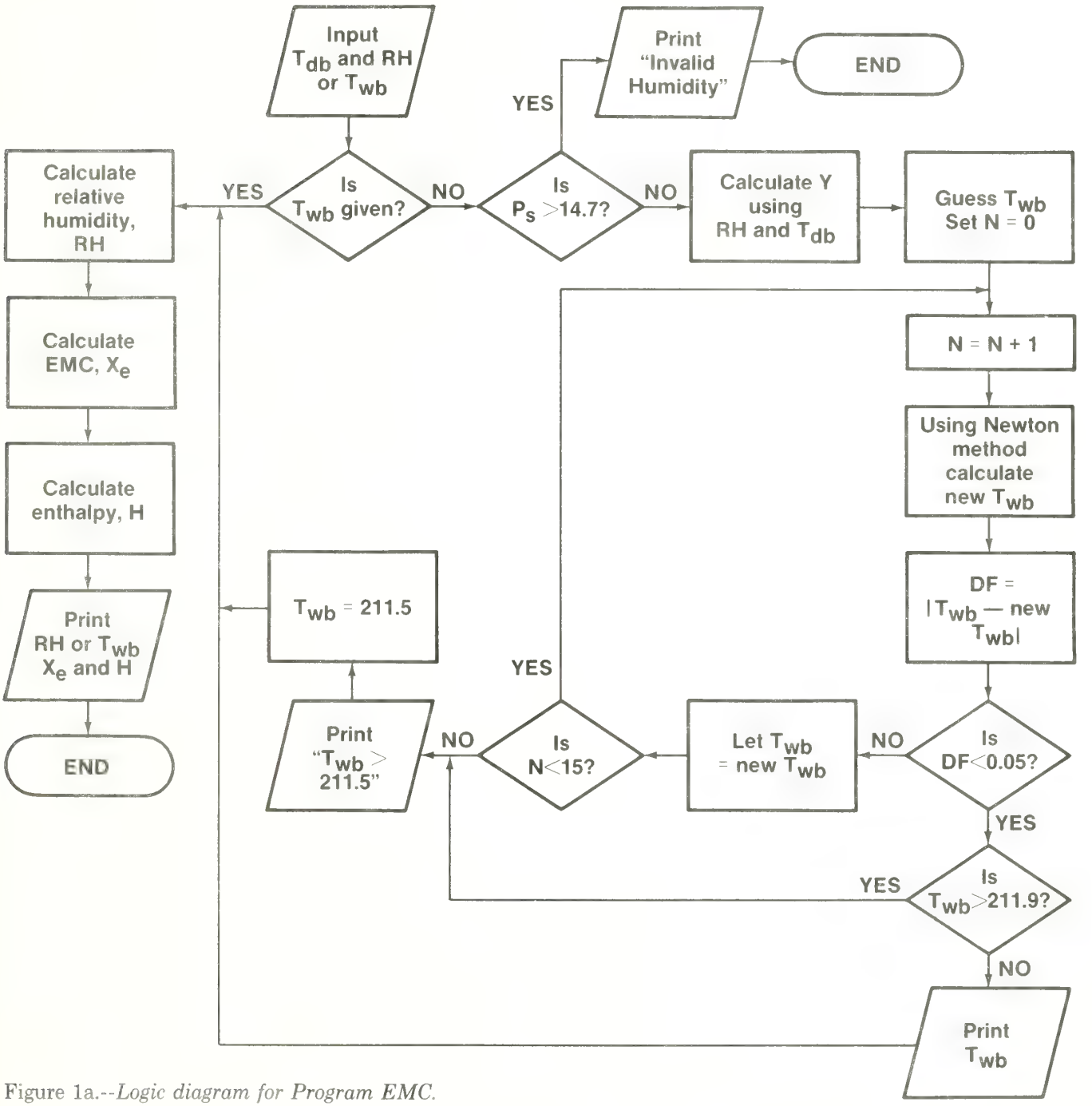

Figure 1a.--*Logic diagram for Program EMC.*

```
 6:COLOR 0:INPUT "TDB=?";TD:INPUT "RH=?";RH
25:TW=0:R1=RH:IF RH>0GOTO 30
27:INPUT "TWB=?";TW
30:LPRINT "   GIVEN:            "
31:COLOR 1:LPRINT USING "###########.#";"TDB =";TDB
32:IF RH>=0LPRINT "RH = ";RH
33:IF RH<0LPRINT "TWB =";TW
34:LPRINT " "
35:COLOR 0:LPRINT "   RESULTS:"
36:COLOR 3:LPRINT " "
40:T=TD:GOSUB 600
41:PD=PS
45:N=0:IF RH>0GOTO 250
50:T=TW
55:GOSUB 600
60:PW=PS:YS=Y2:Y=Y3
72:IF Y<0LET Y=0
75:P=(14.7*Y)/(.622+Y):IF N>0GOTO 90
80:RH=P/PD*100
85:LPRINT "RH = ";RH
90:K1=3.73+.03642*TD-.0001547*TD*TD
95:K2=.674+.001053*TD-.000001714*TD*TD
100:W=216.9+.01961*TD+.00572*TD*TD
105:H1=RH/100
110:EM=((K1*K2*H1)/(1+K1*K2*H1)+K2*H1/(1-K2*H1))*1800/W
115:LPRINT "EMC =";EM
120:HA=.24*(1+8.33E-6*TD)*TD
125:HB=Y*(1061+.444*(1+4.464E-6*TD)*TD)
130:H=HA+HB
135:LPRINT USING "#######.#";"ENTHALPY=";H
190:END
250:P=RH*PD/100
255:Y=(P*0.622)/(14.7-P)
280:TA=TD-20
285:T=TA:GOSUB 600
286:N=N+1
290:P1=PS:F1=Y-Y3
300:TB=TA-.005
305:T=TB:GOSUB 600
310:P0=PS:F0=Y-Y3
360:DR=(F1-F0)/.005
365:TW=TA-(F1/(DR))
367:IF TW<212GOTO 375
368:TA=211
373:GOTO 395
375:DF=ABS (TW-TA)
385:IF DF<.05GOTO 450
390:TA=TW
395:IF N=15GOTO 500
400:GOTO 285
450:LPRINT "TWB =";TW
460:GOTO 50
500:LPRINT "TWB >         211.5"
510:TW=212:GOTO 50
600:T1=T:T=(T+459.6)/1.8
610:PS=EXP (-5800/T+1.391-0.04864*T+0.4176E-4*T*T-.1445E
    -7*(T^3)+6.546*LN T)
620:PS=PS*0.000145
625:IF T1=TDGOTO 670
627:IF PS>14.69GOTO 368
630:Y2=(.622*PS)/(14.7-PS)
635:Y3=((1093-.556*T1)*Y2-.240*(TD-T1))/(1093+.444*TD-T1)
670:RETURN
```

List 1a.--*Program for EMC.*

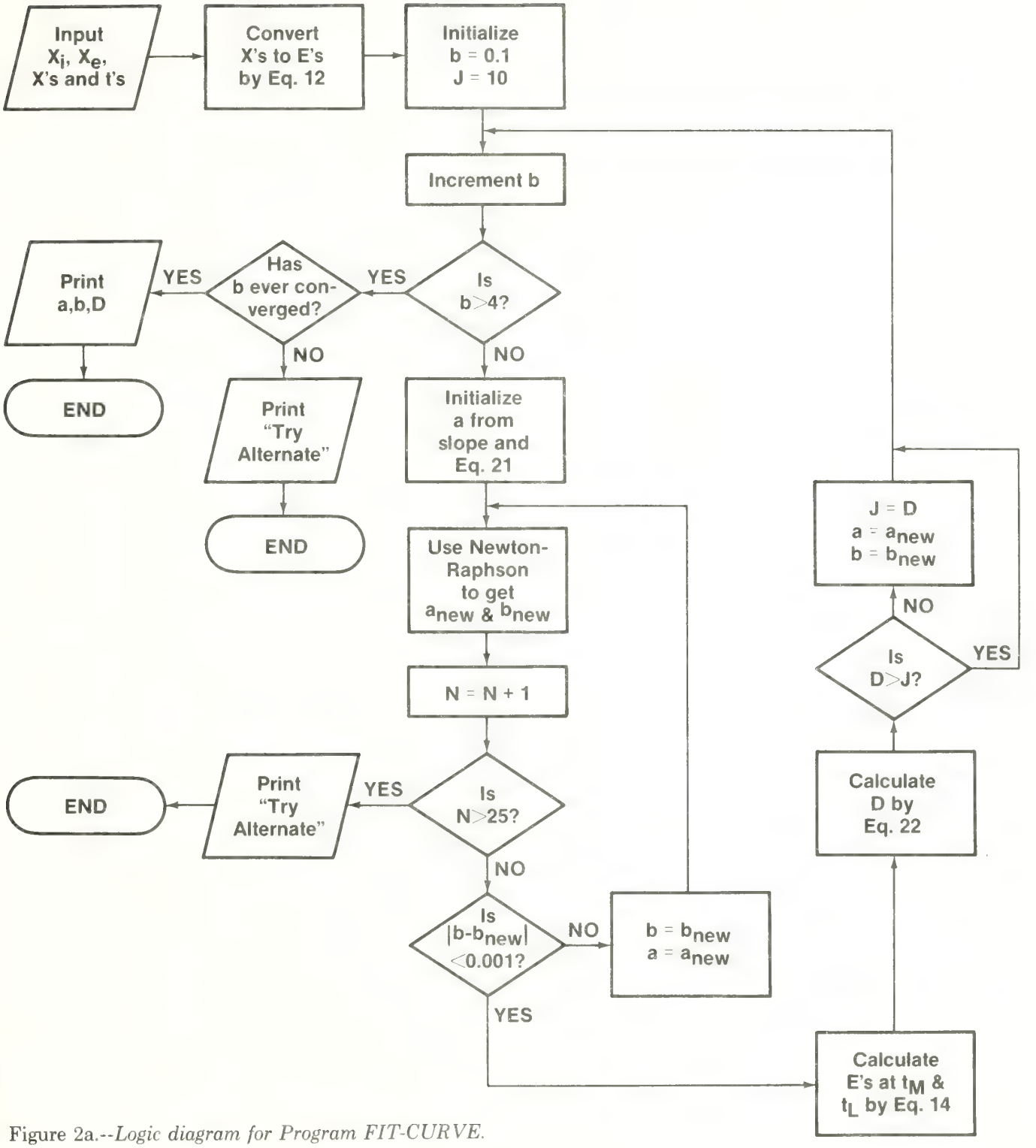

Figure 2a.--*Logic diagram for Program FIT-CURVE.*

```
  5:INPUT "IMC=";J:INPUT "EMC=";B:A=J-B
 10:INPUT "TS=";T1:INPUT "MCS=";E1:INPUT "TM=";T2:E1=(E1-B)/A
 11:INPUT "MCM=";E2:E2=(E2-B)/A:INPUT "TL=";T3:INPUT "MCL=";E3:
    B2=.1:E3=(E3-B)/A:J=10
 17:B2=B2+.05:N=0:COLOR 0
 18:IF B2>.5LET B2=B2+.10
 19:IF B2>1.2LET B2=B2+.4
 21:B=B2:GOSUB 600
 22:A=((1-E1)/(T1)*B*G)^(1/B):IF B2>4GOTO 269
 25:B0=B:G0=G:A0=A
 27:B1=B0+.005:A1=A0+.005:B=B1:GOSUB 600
 55:G1=G:A=A0:B=B0:G=G0:GOSUB 500
 70:FA=D:A=A1:B=B0:G=G0:FB=M:GOSUB 500
 85:FC=D:A=A0:B=B1:G=G1:FE=M:GOSUB 500
100:G=(FC-FA)/.005:R=(D-FA)/.005
115:EZ=(FE-FB)/.005:FZ=(M-FB)/.005
125:X=G*FZ-EZ*R:N=N+1:IF X=0GOTO 17
130:A1=(G*A0+R*B0-FA)*(FZ/X)-(EX*A0+FZ*B0-FB)*(R/X)
131:IF A1<0.005GOTO 17
140:B1=-(G*A0+R*B0-FA)*(EZ/X)+(EZ*A0+FZ*B0-FB)*(G/X)
141:IF B1<.01GOTO 17
142:IF B1>14GOTO 17
143:IF N>25GOTO 280
145:A0=ABS (B1-B0):B=B1:A=A1:GOSUB 600
155:IF A0>.001THEN GOTO 25
215:EZ=(A^B)/(B*G):T=T2:GOSUB 700:FZ=(E-E2)^2
230:T=T3:GOSUB 700:D=((FZ+2*(E-E3)^2)/3)^(0.5):IF D>JGOTO 17
255:J=D:B3=B:A3=A:IF B2>3GOTO 270
259:IF B2<1LET B2=1:GOTO 17
269:IF A3=0GOTO 280
270:LPRINT USING "###.###";"A =";A3:LPRINT "B =";B3:LPRINT " ":
    COLOR 3:LPRINT "D =";J:END
280:LPRINT "TRY ALTERNATE":END
500:D=((A*T3^(1/B))^(B-B2))*(EXP (-A*T3^(1/B)))*((A*T3^(1/B)
    +B-1)/G)-E3
555:M=1-E1-(T1*A^B)/(B*G)+(A^(B+1)*T1^((B+1)/B))/(B*G+G):RETURN
600:M=1:X=B
625:IF B<=1GOTO 645
630:M=M*(B-1):B=B-1:GOTO 625
645:G=B+.5772156*(B^2)+(-.655878)*(B^3)+(-.042003)*(B^4)+
    (.1665386)*(B^5)
650:D=(-.0421977)*(B^6)+(-.009622)*(B^7)+(.007219)*(B^8)+
    (-.001165)*(B^9)
655:G=M/(G+D+(-.0002152)*(B^10)):B=X:RETURN
700:X=0:G=0:N=0:R=1
705:GOTO 765
710:N=N+1:R=R*N
765:X=X+(-1)^N*A^N*T^(N/B)/(N/B+1)/R:D=ABS (X-G)
780:IF  D<0.000001GOTO 790
782:G=X:GOTO 710
790:E=1-(EZ*T*X):RETURN
```

List 2a.--*Program for FIT-CURVE.*

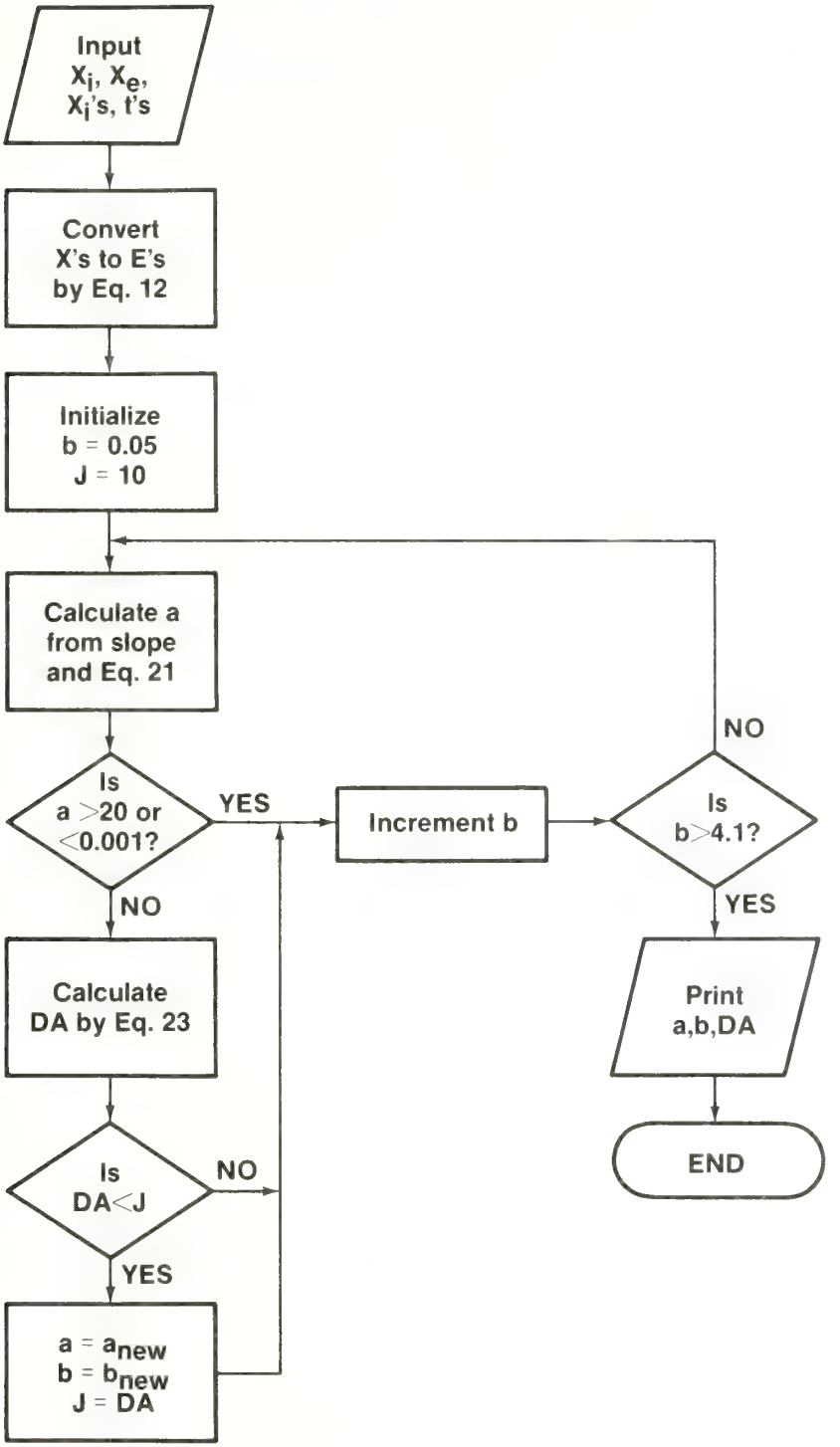

Figure 3a.--*Logic diagram for Program FIT-CURVE-A.*

```
  5:INPUT "IMC=";J:INPUT "EMC=";B:A=J-B
 12:INPUT "TS=";T1:INPUT "MCS=";E1:E1=(E1-B)/A
 13:INPUT "TM=";T2:INPUT "MCM=";E2:E2=(E2-B)/A
 15:INPUT "TL=";T3:INPUT "MCL=";E3:E3=(E3-B)/A
 17:J=10:CSIZE 2
 19:B=0.05
 21:GOSUB 600
 22:A=(B*G*(1-E1)/(T1))^(1/B)
 23:IF A>20GOTO 300
 24:IF A<.001GOTO 300
100:H=(A^B)/(B*G):T=T1:GOSUB 700
105:D1=((E1-E)^2)*.5:T=T2:GOSUB 700
115:D2=(E2-E)^2:T=T3:GOSUB 700
120:D3=((E3-E)^2)*2
125:DF=((D1+D2+D3)/3.5) 0.5
200:IF DF>JGOTO 300
210:J=DF
215:B3=B:A3=A
300:IF B>1.5LET B=B+.25
301:IF B>1.5GOTO 320
305:IF B>.2OLET B=B+.15
306:IF B>.2OGOTO 320
310:B=B+.05
320:IF B<4.1GOTO 21
370:LPRINT USING "###.###";"A =";A3
371:LPRINT "B =";B3:COLOR 3
372:LPRINT " ":LPRINT "DA =";J
373:LPRINT "    "
374:LPRINT "    "
375:LPRINT "    "
380:END
600:M=1:X=B
625:IF B<=1GOTO 645
630:M=M*(B-1):B=B-1:GOTO 625
645:G=B+.5772156*(B^2)+(-.655878)*(B^3)+(-.042003)*(B^4)+
    (.1665386)*(B^5)
650:D=(-.0421977)*(B^6)+(-.009622)*(B^7)+(.007219)*(B^8)+
    (-.001165)*(B^9)
655:G=M/(G+D+(-.0002152)*(B^10)):B=X:RETURN
700:X=0:G=0:N=0:R=1
705:GOTO 765
710:N=N+1:R=R*N
765:X=X+(-1)^N*A^N*T^(N/B)/(N/B+1)/R
766:IF X>400GOTO 300
768:IF X<-400GOTO 300
775:D=ABS (X-G)
780:IF  D<0.000001GOTO 790
782:G=X:GOTO 710
790:E=1-(H*T*X):RETURN
```

List 3a.--*Program for FIT-CURVE-A.*

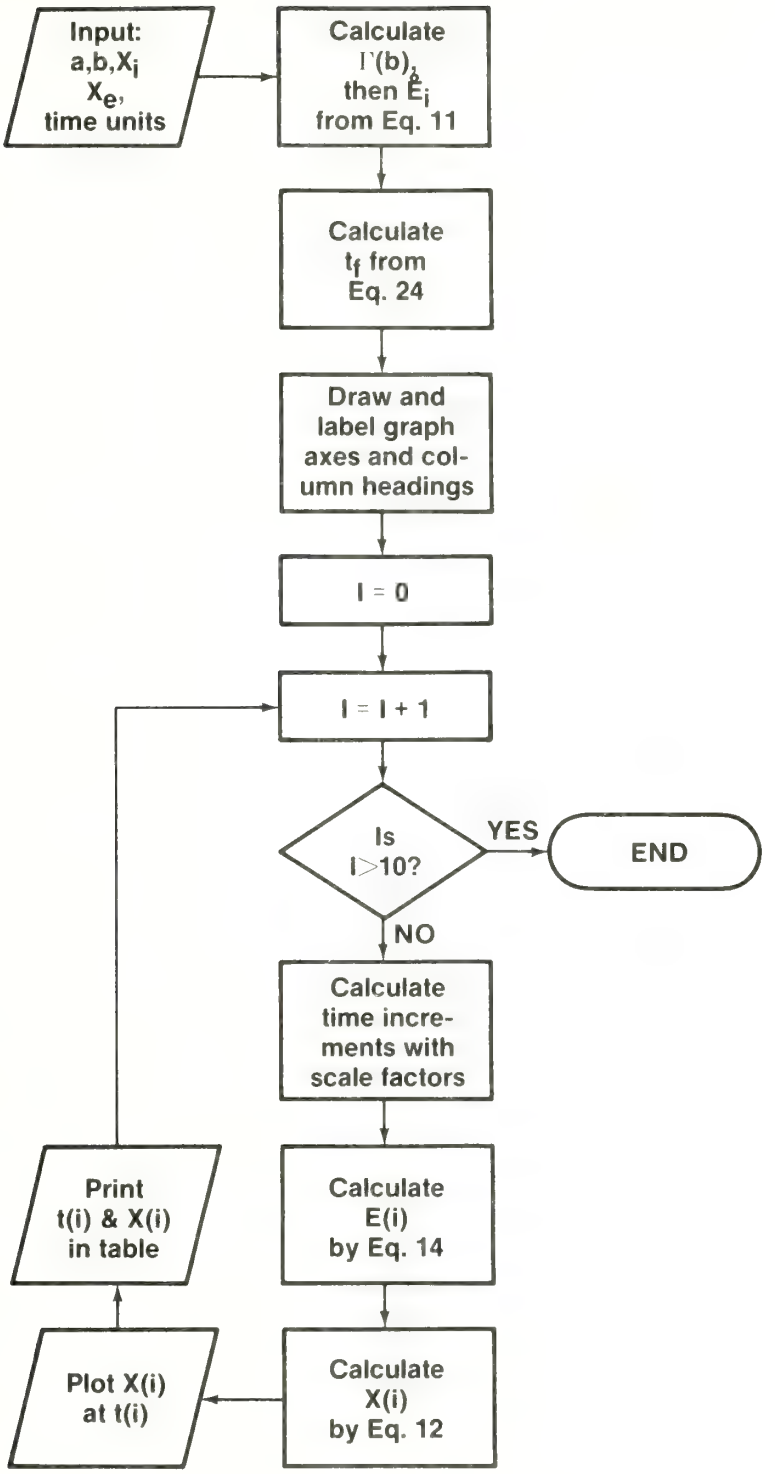

Figure 4a.--*Logic diagram for Program DRY-CURVE-1.*

```
10:INPUT "A=?";A
15:INPUT "B=?";B
16:INPUT "IMC=?";Z
17:S=1.5+2*B
18:INPUT "EMC=";Y
19:INPUT "TIME UNITS=?";A$
20:T=1
22:X=B
25:IF B=1GOTO 45
30:T=T*(B-1)
35:B=B-1
40:GOTO 25
45:G=B+.5772156*(B^2)+(-.655878)*(B^3)+
     (-.042003)*(B^4)+(.1665386)*(B^5)
50:D=(-.0421977)*(B^6)+(-.009622)*(B^7)+
     (.007219)*(B^8)+(-.001165)*(B^9)
55:H=(-.0002152)*(B^10)
60:G=(G+D+H)/T
70:EO=(1/X)*G*(A^X)
72:B=X
75:F=(S/A)^B
106:G=0
109:H=0
110:GRAPH
125:CSIZE 1
130:COLOR 1
135:LPRINT "          MOISTURE CONTENT, MC"
145:GLCURSOR (30,-34):SORGN
147:FOR I=1TO 4
148:H=H-64
149:GLCURSOR (0,H)
150:LPRINT "-"
152:NEXT I
155:GLCURSOR (-30,-108)
156:ROTATE 1
160:LPRINT "TIME,  ";A$
175:LINE (0,0)-(210,0)
180:LINE (0,0)-(0,-264)
181:LINE (-10,-322)-(210,-322)
182:LINE (160,-360)-(160,-280)
235:GLCURSOR (163,-282)
239:T=0:GOSUB 600
240:LPRINT "T(";A$;")   MC"
241:P=5
242:IF C>25LET P=10
244:IF C>50LET P=20
245:IF C>100LET P=30
246:IF C>150LET P=40
247:IF C>200LET P=50
248:IF C>250LET P=65
249:FOR I=1TO 5
250:G=G+35:D=I*P
255:GLCURSOR (G,29)
260:LPRINT USING "####";D
265:LPRINT " -"
270 NEXT I
275:X=175/C
280:H=26
281:GLCURSOR (-10,5)
282:LPRINT "0"
285:IF F<=2LET MU=0.5
286:IF F<=1LET MU=0.25
290:IF F<=2GOTO 345
295:MU=INT (F/4+1)
345:FOR I=1TO 4
350:H=H-64
355:GLCURSOR (-10,H)
360:LPRINT USING "####.##";MU*I
365:NEXT I
366:GLCURSOR (160,-195)
367:LPRINT USING"###.####";"A =";A
368:GLCURSOR (135,-195)
369:LPRINT "B =";B
370:GLCURSOR (110,-195)
371:LPRINT USING "###.##";"EMC =";Y
374:COLOR 0
375:EA=175*C/(P*5)
380:QA=0
382:H=160:GOTO 401
385:FOR I=1TO 16
387:IF I 4LET I=I+1
390:T=I+MU*.25
391:QB=QA-16
392:IF I>4LET QB=QB-16
394:GOSUB 600
397:EB=C*175/(P*5)
400:LINE (EA,QA)-(EB,QB)
401:H=H-15
403:GLCURSOR (H,-275)
405:LPRINT USING "####.##";T;C
410:IF T=0GOTO 385
411:QA=QB
412:EA=EB
413:GLCURSOR (EB,QB)
414:IF E<.004GOTO 417
415:NEXT I
417:GLCURSOR (0,-485)
418:END
600:TT=0:N=0:R=1:PT=0
607:IF T=0LET E=1.0
608:IF T=0GOTO 717
609:GOTO 665
610:N=N+1:R=R*N
665:S=(((-1)^N)*(A^N)*(T^(N/B)))/
    ((N/B+1)*R)
685:TT=TT+S
690:D=ABS (TT-PT)
695:IF D<0.000001GOTO 715
700:PT=TT:GOTO 610
715:E=1-(EO*T*TT)
717:C=E*(Z-Y)+Y
720:RETURN
```

List 4a.--*Program for DRY-CURVE-1.*

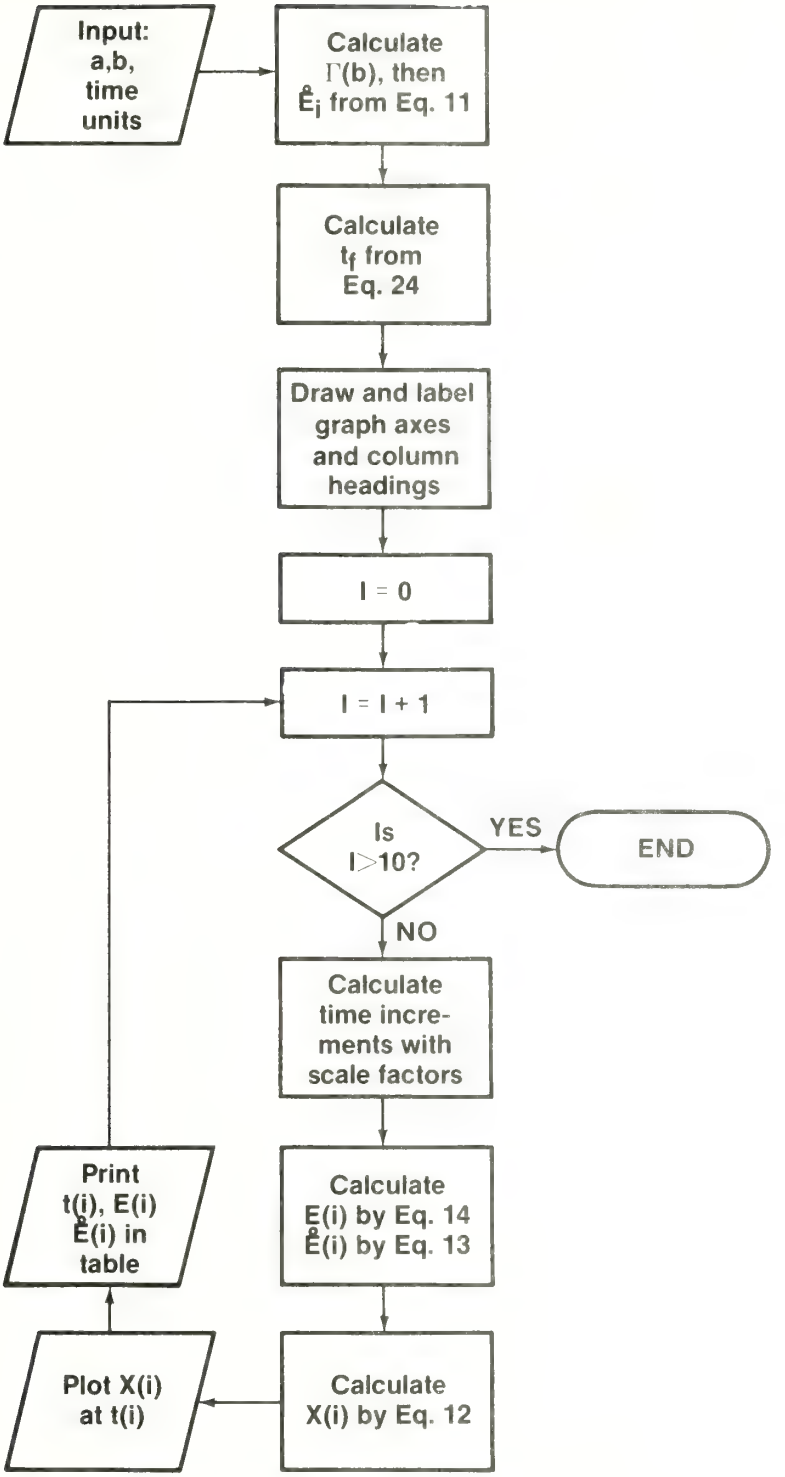

Figure 5a.--*Logic diagram for Program DRY-CURVE-2.*

```
 10:INPUT "A=?";A
 15:INPUT "B=?";B
 17:S=1.5+2*B
 19:INPUT "TIME UNITS=?";A$
 20:T=1
 22:X=B
 25:IF B<=1GOTO 45
 30:T=T*(B-1)
 35:B=B-1
 40:GOTO 25
 45:G=B+.5772156*(B^2)+(-.655878)*(B^3)+
      (-.042003)*(B^4)+(.1665386)*(B^5)
 50:D=(-.0421977)*(B^6)+(-.009622)*(B^7)+
      (.007219)*(B^8)+(-.001165)*(B^9)
 55:H=(-.0002152)*(B^10)
 60:G=(G+D+H)/T
 70:EO=(1/X)*G*(A^X)
 72:B=X
 75:F=(S/A)^B
106:G=0
109:H=0
110:GRAPH
125:CSIZE 1
130:COLOR 1
135:LPRINT "         RELATIVE MOISTURE, E"
145:GLCURSOR (30,-31):SORGN
147:FOR I=1TO 4
148:H=H-64
149:GLCURSOR (0,H)
150:LPRINT "-"
152:NEXT I
155:GLCURSOR (-30,-108)
156:ROTATE 1
160:LPRINT "TIME  ";A$
175:LINE (0,0)-(210,0)
180:LINE (0,0)-(0,-264)
181:LINE (-10,-322)-(210,-322)
182:LINE (160,-400)-(160,-280)
183:LINE (-10,-360)-(210,-360)
235:GLCURSOR (163,-282)
240:LPRINT "T(";A$;")   E    RDR"
245:FOR I=1TO 5
250:G=G+35:D=I*.2
255:GLCURSOR (G,28)
260:LPRINT USING "##.#";D
265:LPRINT " -"
270"NEXT I
280:H=26
281:GLCURSOR (-10,5)
282:LPRINT "0"
285:IF F<=2LET MU=0.5
286:IF F<=1LET MU=0.25
290:IF F<=2GOTO 345
295:MU=INT (F/4+1)
345:FOR I=1TO 4
350:H=H-64
355:GLCURSOR (-10,H)
360:LPRINT USING "####.##";MU*I
365:NEXT I
366:GLCURSOR (160,-195)
367:LPRINT USING"###.####";"A =";A
368:GLCURSOR (125,-195)
369:LPRINT "B =";B
371:COLOR 3
375:EA=175
380:QA=0
382:H=160
383:T=0:GOTO 394
385:FOR I=1TO 16
387:IF I>4LET I=I+1
390:T=1+MU*.25
391:QB=QA-16
392:IF I>4LET QB=QB-16
394:GOSUB 600
396:IF T=0GOTO 401
397:EB=C*175
400:LINE (EA,QA)-(EB,QB)
401:H=H-15
403:GLCURSOR (H,-275)
405:LPRINT USING "####.##";T;E
409:LPRINT USING "###.##^";RR
410:IF T=0GOTO 385
411:QA=QB
412:EA=EB
413:GLCURSOR (EB,QB)
414:IF E<.004GOTO 417
415:NEXT I
417:GLCURSOR (0,-485)
418:END
600:RR=EO*(EXP (-A*T^(1/B)))
605:TT=0:N=0:R=1:PT=0
607:IF T=0LET E=1.0
608:IF T=0GOTO 720
610:GOTO 665
625:N=N+1:R=R*N
665:S=(((-1)^N)*(A^N)*(T^(N/B)))/
    ((N/B+1)*R)
685:TT=TT+S
690:D=ABS (TT-PT)
695:IF D<0.000001GOTO 715
700:PT=TT:GOTO 625
715:E=1-(EO*T*TT)
720:RETURN
```

List 5a.--*Program for DRY-CURVE-2.*

APPENDIX C — EXAMPLE PROBLEM

The drying of ¾-inch-thick pine sapwood at 234°F dry-bulb temperature and 210°F wet-bulb temperature in a laboratory dryer will serve as an example to demonstrate the use of computer package DRYPAC (Kollman and Schneider 1961). First, T_{db} and T_{wb} are input to Program EMC to obtain an X_e of 5.9 percent (fig. 6a). Values of X_i, X_e, X_S, t_S, X_M, t_M, X_L, and t_L are then input to Program FIT-CURVE which converge to a value of a and b in less than 3 minutes with a value of D of only 0.007, indicating a good fit to the three data points. Finally, X_i, X_e, a, and b are input to Program DRY-CURVE-1 for a complete predicted curve, which closely fits all the data points (fig. 6a).

A practical question which can be answered by this example, is "How long would be required to dry this wood to 15 percent moisture content?" From figure 6a, 5.7 hours is necessary.

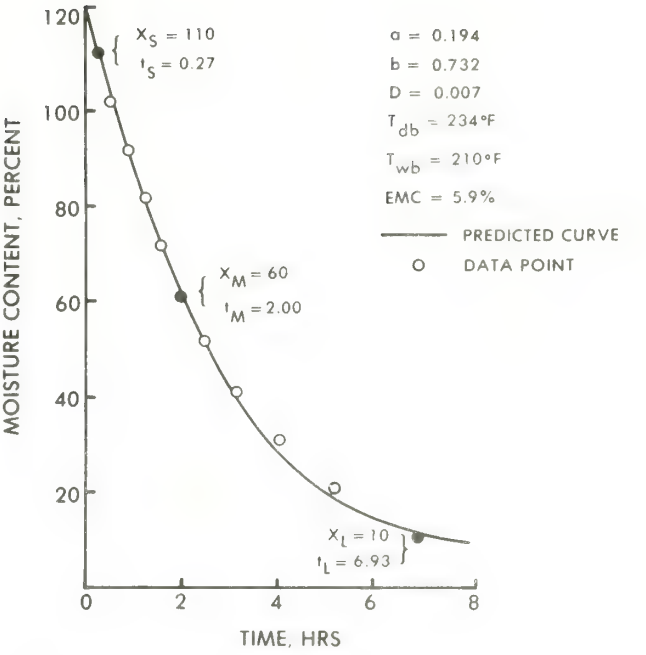

Figure 6a.--*Plot of moisture content versus time for drying pine sapwood (Kollmann and Schneider 1961). The solid line is the predicted curve and the solid circles are the input data points for Program DRY-CURVE-1.*

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Forest Management Opportunities for Michigan, 1981-1990

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1985

FOREST MANAGEMENT OPPORTUNITIES FOR MICHIGAN, 1981-1990

W. Brad Smith, *Mensurationist*,
and **John S. Spencer, Jr.**, *Principal Resource Analyst*

Between 1977 and 1981 the Forest Inventory and Analysis Project at the North Central Forest Experiment Station, in cooperation with the Michigan Department of Natural Resources (DNR) and interested forest industries, inventoried Michigan's forest resources. This survey, part of a nationwide effort mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974, estimated the area of commercial forest land and the volume of timber, growth, mortality, removals, and biomass in the State. In this paper we use data collected from the inventory to estimate the area of commercial forest by kind of forest management opportunity to enhance roundwood production for the decade after the inventory (1981-1990). We also estimate the volume of timber that could be produced as a result of these treatments.

Michigan's commercial forest area of 17.5 million acres in 1980 supported 19.1 billion cubic feet of growing stock, including 47.7 billion board feet[1] of sawtimber. The predominant forest type was maple-birch, which accounted for 6.1 million acres (35 percent) of the commercial forest. The aspen type followed with 3.4 million acres (19 percent) of the area. Poletimber stands totaled 7.8 million acres (44 percent) of the commercial area. Half of the stands in the State are 50 years of age or younger, indicating that preharvest treatments might be appropriate over a large area. Nonindustrial private parties own 53 percent of the commercial forest, suggesting government support in the form of incentive payments, equitable taxation, and education may help accomplish forest treatments. Because only 15 percent of the State's commercial forest is farther than 1 mile from a maintained road[2], accessibility to areas to be treated is not a major problem.

Forest management opportunities and their criteria for the decade 1981 to 1990 were identified with the help of personnel from the Michigan DNR and from published timber management guides. Treatments selected are as follows:

Stand conversion.—clearcutting of stands with low commercial potential and artificially regenerating with tree species of high commercial potential.

Restock.—artificially regenerating (planting or seeding) areas not adequately stocked[3] with growing-stock trees of desirable species or preparing the site to encourage the establishment of natural regeneration.

Harvest.—the final cut in a mature forest stand. In this study the final cut for all forest types except the maple-birch type is assumed to be a clearcut. As explained in greater detail under *Methods*, we assume that some maple-birch stands will be managed under the shelterwood system but that the majority of maple-birch stands will be managed under the tree selection system. For stands under the shelterwood system, the last shelterwood cut is assumed to be the final cut and is included under the harvest treatment. Cuts made by the tree selection system are included under the thinning treatment. We assumed that all harvest cuts will be followed by adequate natural or artificial regeneration. Therefore, harvest acres and volumes are not shown a second time under either the stand conversion or restocking treatments.

Timber stand improvement.—a noncommercial or precommercial partial cut in a forest stand prior to the final harvest cut such as weeding or cleaning. For this study only poletimber stands yielding less than 3 cords per acre are included in this treatment for all forest types except the maple-birch type. Sawtimber stands of the maple-birch type that ordinarily would have been scheduled for thinning except that they would yield less than 3 cords per acre were also scheduled for timber stand improvement.

[1] *International 1/4-inch rule.*

[2] *Any road—hard-topped or other surface—that is plowed or graded at least once a year.*

[3] *Stocking is greater than on nonstocked areas. Stands whose basal area per acre is less than 19 + (0.38 × stand age) and whose stand age is from 10 to 80 years are selected for restocking treatment.*

Release.—removing inhibiting overstory trees of less desirable species from a stand to promote the growth of more desirable understory trees.

Thin.—a commercial partial cut in a forest stand prior to the final harvest cut. Thinning operations must yield at least 3 cords per acre of growing stock. In this report tree selection cuts in the maple-birch type are considered to be thinning treatments.

Some commercial forest land in the State is not included under any of the above treatments but is included in one of the following categories in order to incorporate the entire commercial area:

No treatment.—the stands' condition does not warrant any timber management activity during the current decade.

Nonstocked areas.—commercial forest land currently less than 16.7 percent stocked with growing-stock trees. These areas have little potential for stocking improvement in the near future without management intervention. Some of these areas will be regenerated. However, they differ from stands in the restock treatment because they are more sparsely stocked, and by the need to consider each area separately to judge the efficacy of treatment because site quality is usually unknown.

Hydric sites.—commercial forest land on very wet sites where excess water seriously limits both growth and species occurrence and precludes most commercial timber management activity. Timber can be harvested on these sites when the soil freezes.

No single, true evaluation exists for the management opportunities in Michigan. The rationale for and criteria used in treating stands will differ widely among individuals. The findings presented in this paper result from only one of many possible sets of treatment options.

ASSUMPTIONS

We made three major assumptions in conducting this study: (1) the area of commercial forest land in the State (17.5 million acres in 1980) will decline to 17.4 million by 1985 and to 17.3 million by 1990, (2) all commercial forest land is available for treatment, and (3) markets exist for the sale of all forest products of all commercial species. Because these assumptions may not be realized, estimates generated from this study should be discounted accordingly. We did not consider possible economic, social, or political constraints on management opportunities.

METHODS

We used a modified version of the computer model Stand and Tree Evaluation and Modeling System (STEMS)[4] to project Michigan's forest resource 5 years ahead. In this paper we will call this model FIASTEMS (Forest Inventory and Analysis STEMS). Although forest management opportunities are projected for a decade, actual treatments would be performed each year. Estimates of timber volume removed during the treatment period, should reflect the net growth that would accrue between 1980, the inventory year, and the treatment year. Consequently, we projected each permanent sample plot 5 years to estimate the average growth for the decade before evaluating treatments.

Plot data from the 1980 Michigan forest inventory were used as input to STEMS. STEMS "grew" each plot for 5 years and calculated areas and volumes represented by the plots. Following the projection we used the process illustrated in figure 1 to determine the appropriate treatment. The computer first examined plot data to exclude hydric sites and nonstocked areas. These classes of commercial forest land were set aside and were not included in any of the treatments that follow. In practice, however, hydric sites and nonstocked areas would be considered for treatment on a stand-by-stand basis. Some of this land would be deemed suitable for some kind of forest management.

Stand Conversion

Next, the computer checked the site index of plots in several forest types where timber management is the primary objective to determine whether the stands should be converted to another type. Stands in the maple-birch and oak-hickory types whose site index was less than 55 feet and stands in the aspen-birch type whose site index was less than 60 feet ("off-site" stands) were targeted for conversion to the red pine type (table 1). Such stands are considered unlikely to produce economically viable crops of industrial roundwood if the present forest type prevails. If converted to red pine, these sites could be expected to produce commercial timber crops.

Restock

The remaining plots were examined to single out those that were inadequately stocked with trees. With the help of the FIASTEMS computer program we scanned the records of plots representing nonseedling stands aged 11 to 80 years to find those

[4]*U.S. Department of Agriculture, Forest Service. A description of STEMS: The stand and tree evaluation and modeling system. Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 18 p.*

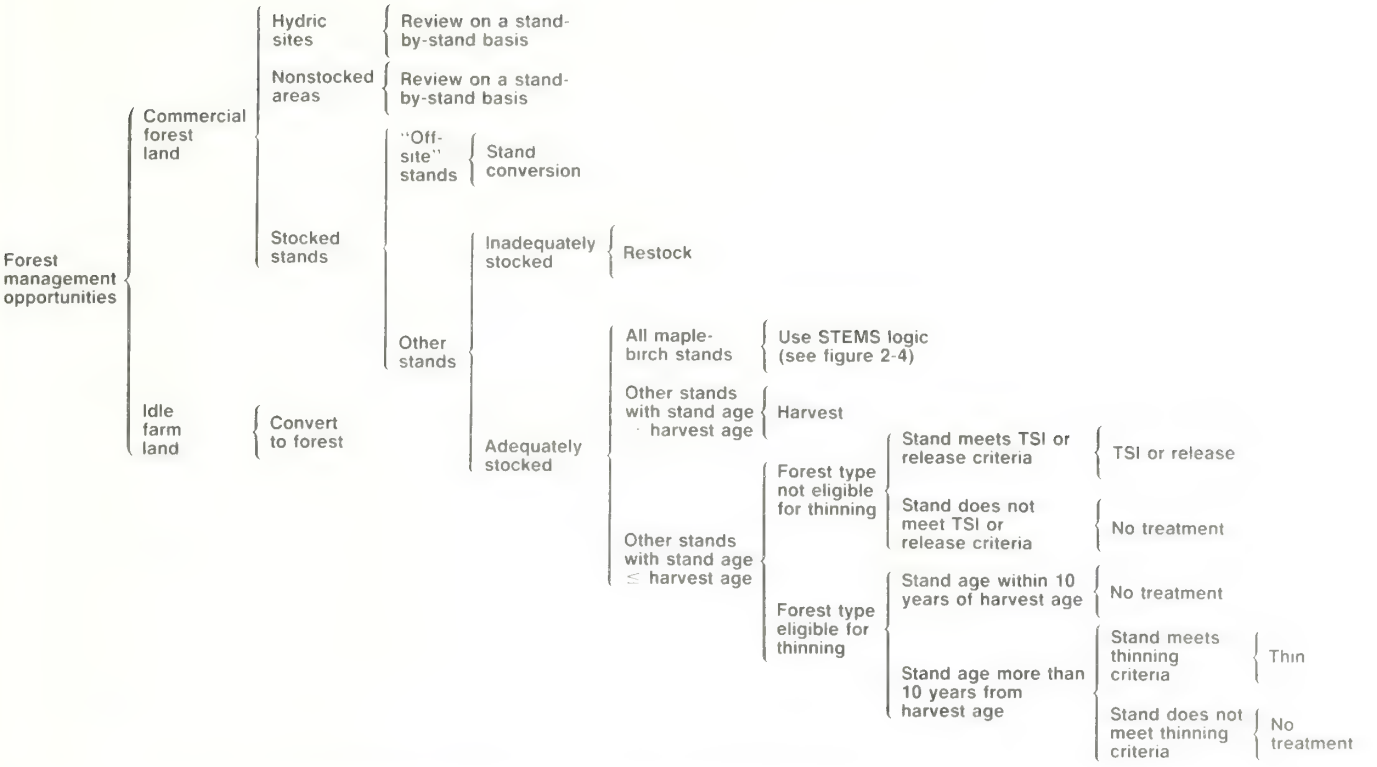

Figure 1.—*Diagram of logic used by the computer to sort Michigan plots into forest management opportunities, 1981-1990.*

whose basal area per acre was less than 19 + (0.38 × stand age).[5] Such stands are not expected to reach an adequate level of stocking by the end of the rotation and were targeted for restocking to forest trees. Stands in all forest types except the paper birch type were scheduled for restocking using this logic. In practice, however, little or no artificial regeneration is performed presently in some types—notably the black spruce, northern white-cedar, tamarack, and aspen types. For these types, the restocking area should be regarded as a measure of the number of inadequately stocked acres on which restocking may one day be a silviculturally viable management option.

Harvest

Next, the FIASTEMS computer program allowed us to separate plots in the maple-birch forest type from the plots that remained and to treat them separately as described below. FIASTEMS scanned the stand age of remaining plots and compared it to the harvest age recommended for each forest type by Michigan DNR foresters (table 1). Plots whose stand age equalled the recommended harvest age at any time during the period 1981-1990 were scheduled for harvesting.

Plots in the maple-birch type were treated differently by the computer program because all-aged rather than even-aged silvicultural systems are used to manage this type. The computer program recognizes three kinds of maple-birch stands: (1) those with a strong yellow birch component, (2) those with a strong hemlock component, and (3) all other maple-birch stands, as explained in more detail below. The logic followed by FIASTEMS for maple-birch plots is shown in figures 2-4 and is modified from Brand (1981)[6]. Brand cited several objectives and assumptions with regard to using this logic:

1. Maintain or develop all-aged maple-birch stands.
2. If possible manage for timber production, particularly for saw and veneer logs.
3. If yellow birch basal area of all live trees is more than 25 percent of the maple-birch basal area, the stand is considered primarily yellow birch (stand composition 1). Maintain these stands using the shelterwood silvicultural system.
4. If hemlock basal area of all live trees is more than 50 percent of the maple-birch basal area, the

[5]*A general equation developed by USDA Forest Service researchers to identify nonseedling stands in which stocking, in relation to age, is so low that the stands are not expected to reach a stocking level adequate for commercial timber production by rotation age.*

[6]*Brand, Gary J. Simulating timber management in Lake States forests. Gen. Tech. Rep. NC-69, St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1981. 25 p.*

Table 1.--Management criteria, Michigan, 1981-1990

Forest type	Stand conversion	Restock	Rotation (harvest) age	Pre-thinning basal area	Post-thinning basal area	Timber stand improvement[1/]	Release
			Years	Square feet per acre			
Jack pine	no	yes	50		no	2/	2/
Red pine	no	yes	60	140	90	2/	no
White pine	no	yes	80	140	90	2/	2/
White spruce	no	yes	60		2/	2/	2/
Black spruce	no	yes[3/]	70		no	no	no
Balsam fir	no	yes[3/]	50		2/	2/	2/
Tamarack	no	yes[3/]	60		no	no	no
Northern white-cedar	no	yes[3/]	80		no	2/	2/
Oak-hickory	Site index <54	yes	70		2/	2/	no
Elm-ash-maple	no	yes	70		no	no	no
Maple-birch	Site index <54	yes	2/		2/	2/	2/
Aspen	Site index <59	yes[3/]	40		no	no	no
Paper birch	Site index <59	yes[3/]	50		no	no	no
Exotic	no	yes	60		no	no	no

1/ Scheduled only for poletimber stands yielding less than 3 cords of growing stock per acre.

2/ Use management criteria built into the Stand and Tree Evaluation and Modeling System (STEMS). See Brand, Gary J. Simulating timber management in Lake States forests. Gen. Tech. Rep. NC-69. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1981. 25 p.

3/ Presently this forest type is seldom artificially regenerated.

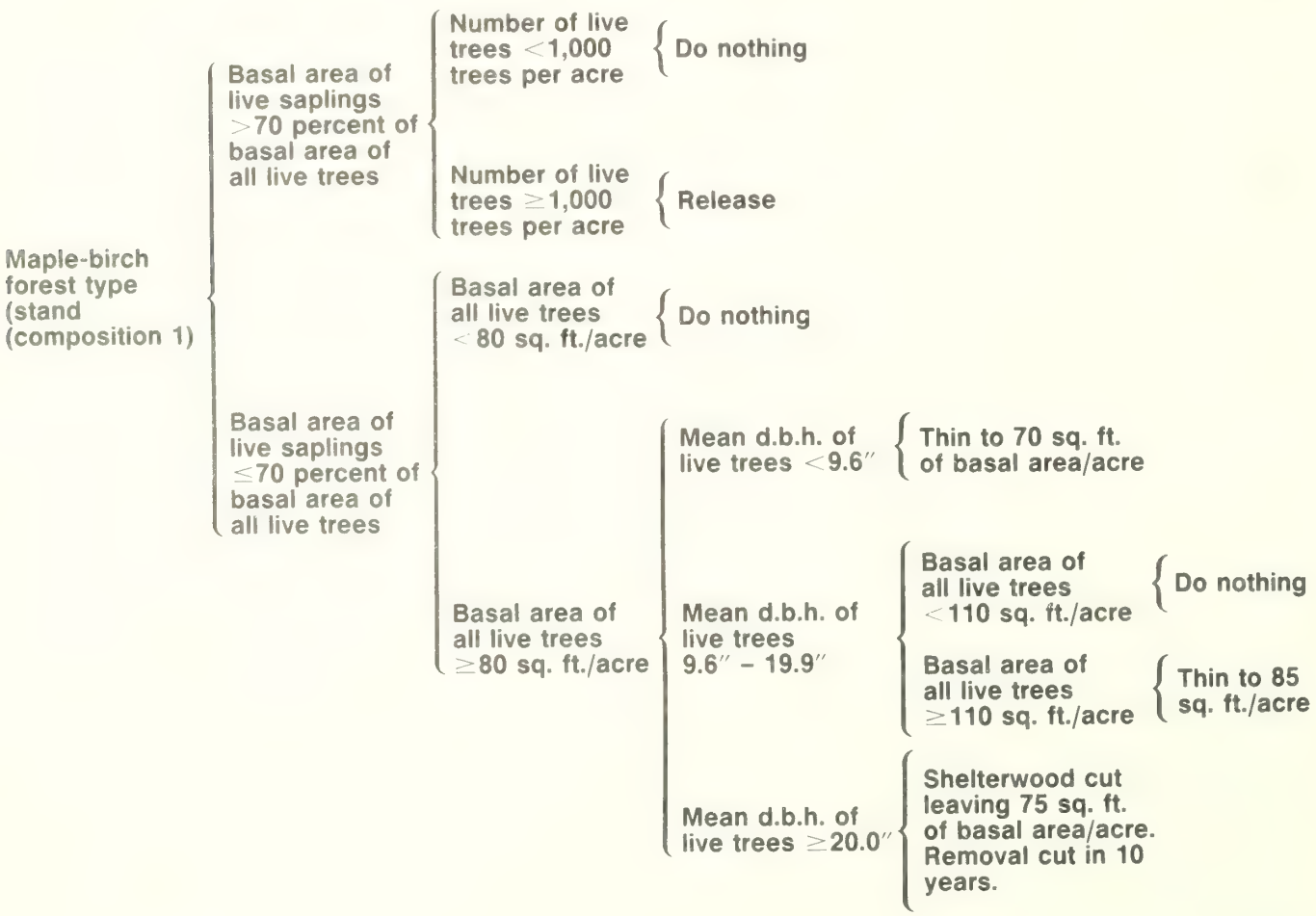
Maple-birch forest type (stand (composition 1)
Basal area of live saplings >70 percent of basal area of all live trees
Number of live trees <1,000 trees per acre
Do nothing
Number of live trees ≥1,000 trees per acre
Release
Basal area of live saplings ≤70 percent of basal area of all live trees
Basal area of all live trees <80 sq. ft./acre
Do nothing
Basal area of all live trees ≥80 sq. ft./acre
Mean d.b.h. of live trees <9.6″
Thin to 70 sq. ft. of basal area/acre
Mean d.b.h. of live trees 9.6″ – 19.9″
Basal area of all live trees <110 sq. ft./acre
Do nothing
Basal area of all live trees ≥110 sq. ft./acre
Thin to 85 sq. ft./acre
Mean d.b.h. of live trees ≥20.0″
Shelterwood cut leaving 75 sq. ft. of basal area/acre. Removal cut in 10 years.

Figure 2.—*Diagram of logic used by the computer to sort plots into treatment classes for those stands in the maple-birch forest type that are primarily yellow birch (stand composition 1).*

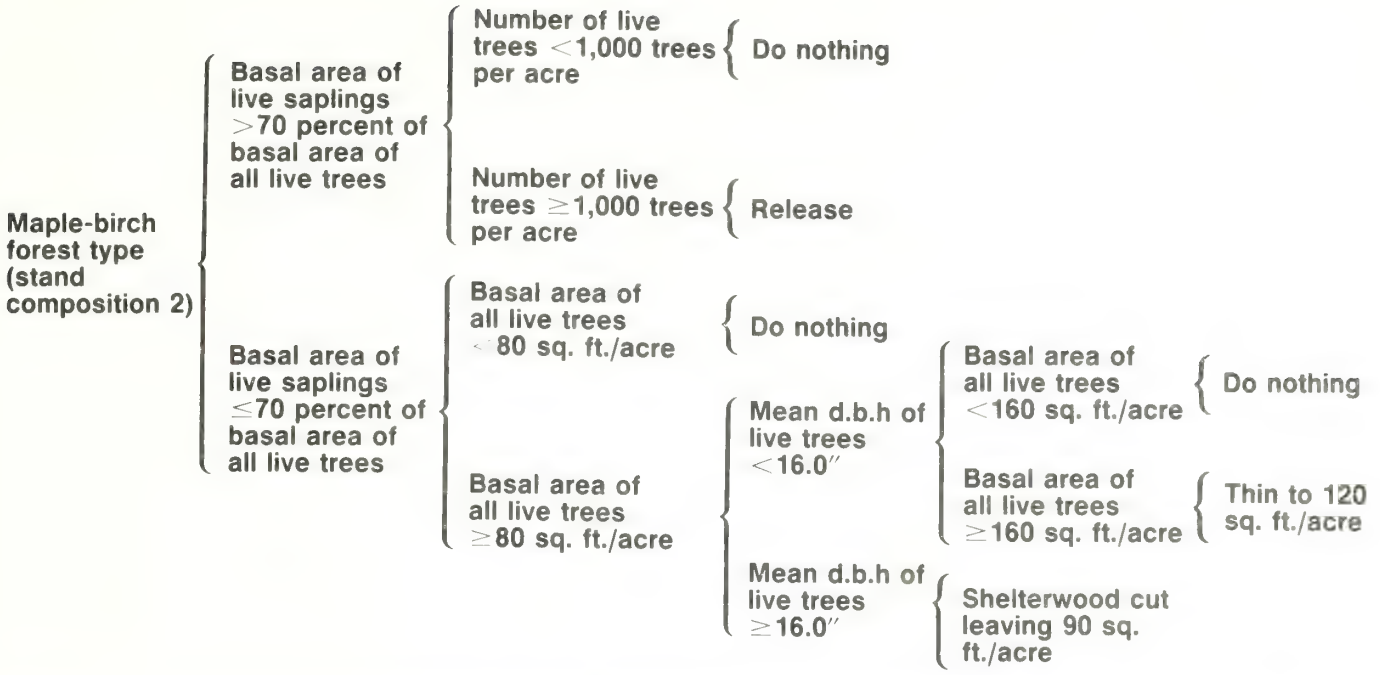
Maple-birch forest type (stand composition 2)
Basal area of live saplings >70 percent of basal area of all live trees
Number of live trees <1,000 trees per acre
Do nothing
Number of live trees ≥1,000 trees per acre
Release
Basal area of live saplings ≤70 percent of basal area of all live trees
Basal area of all live trees <80 sq. ft./acre
Do nothing
Basal area of all live trees ≥80 sq. ft./acre
Mean d.b.h of live trees <16.0″
Basal area of all live trees <160 sq. ft./acre
Do nothing
Basal area of all live trees ≥160 sq. ft./acre
Thin to 120 sq. ft./acre
Mean d.b.h of live trees ≥16.0″
Shelterwood cut leaving 90 sq. ft./acre

Figure 3.—*Diagram of logic used by the computer to sort plots into treatment classes for those stands in the maple-birch forest type that are primarily hemlock (stand composition 2).*

stand is considered primarily hemlock (stand composition 2). Maintain these stands using the shelterwood silvicultural system.

5. If yellow birch basal area is less than 25 percent or hemlock basal area is less than 50 percent—the majority of the maple-birch type—the stand is considered maple-birch (stand composition 3). Maintain these stands using the tree selection system.

Brand also provided marking rules that suggested the species, tree class, and d.b.h. of trees to be removed in partial cuts and in timber stand improvement.

Thinning

The remaining plots, whose stand age would be less than harvest age during the decade, were scanned to determine if the forest type was one considered to be eligible for thinning. Forest managers from the Michigan DNR suggested the following list of types for which thinning was considered silviculturally viable: Red pine, white pine, white spruce, balsam fir, oak-hickory, and maple-birch.

Plots in these types were further scanned to identify those whose stand age would equal harvest age during the decade 1991-2000—stands that would be ready for harvest within 10 years of those presently scheduled for harvest. Such stands were designated as needing no treatment. Plots whose stand age was younger and, therefore, would not be ready for harvest within 10 years of "harvest" plots were then examined to determine whether the stand met the criteria for thinning (as shown in Brand 1981). (Basal area initiating thinning in the red pine and white pine forest types was changed to 140 square feet per acre from that shown by Brand (1981), and post-thinning basal area was changed to 90 square feet per acre as shown in table 1.) These criteria differed for each forest type but generally stands were chosen to be thinned based on stand-age, tree mean d.b.h., and basal area of components of the stand. Examples of the criteria used for the maple-birch forest type are shown in figures 2 to 4. Stands that did not meet thinning criteria were considered to need no treatment.

Timber Stand Improvement and Release

The plots that remained, those not eligible for thinning, were scanned to determine if they were candidates for timber stand improvement (TSI) and release. Forest types suggested by Michigan DNR forest managers as being such candidates are:

TSI	Release
Jack pine	Jack pine
Red pine	White pine
White pine	White spruce
White spruce	Balsam fir
Balsam fir	Northern white-cedar
Northern white-cedar	Maple-birch
Oak-hickory	
Maple-birch	

Plots in these forest types were then analyzed by FIASTEMS to find out if they met the criteria for

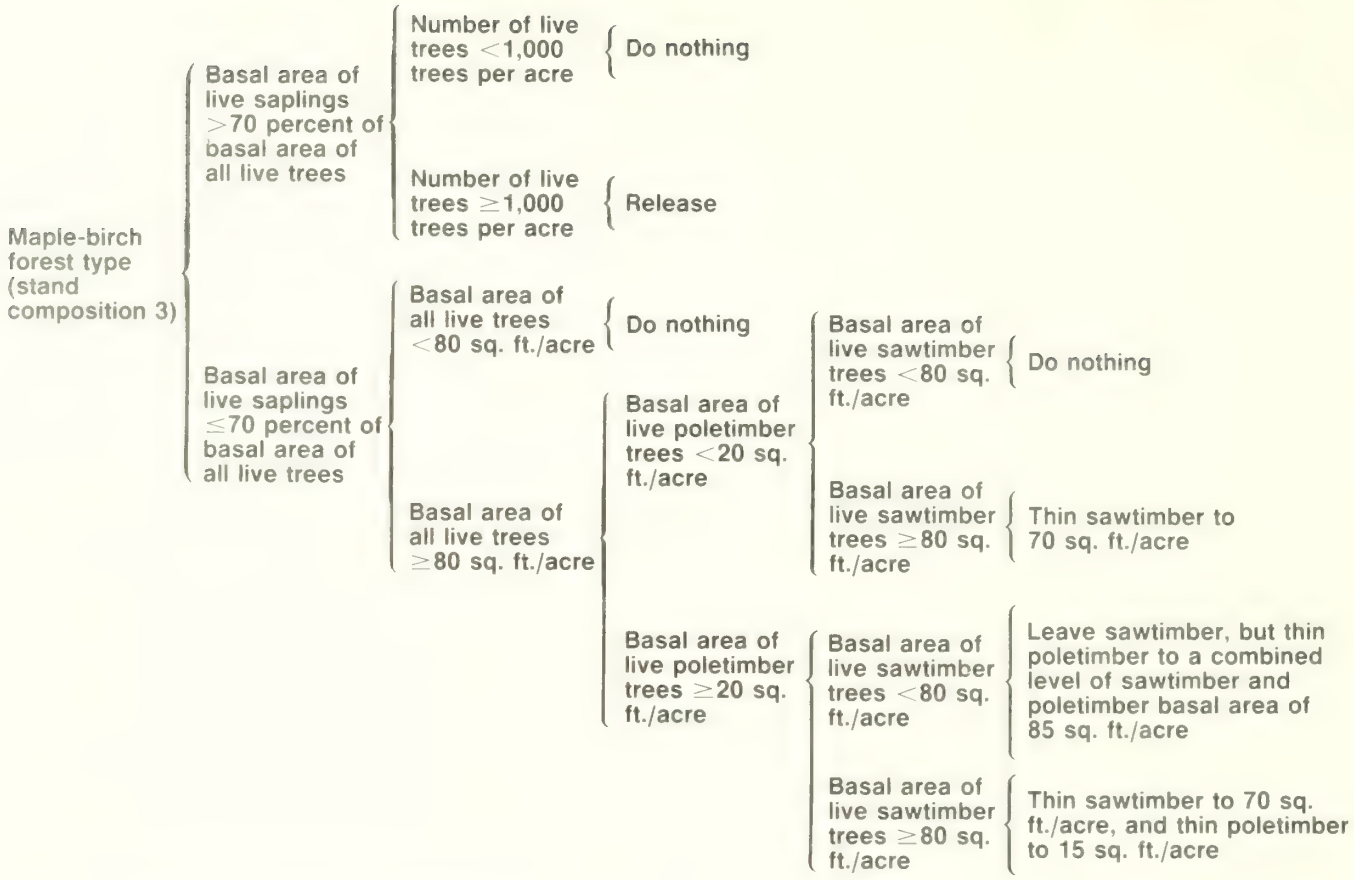
Maple-birch forest type (stand composition 3)
Basal area of live saplings >70 percent of basal area of all live trees
Number of live trees <1,000 trees per acre
Do nothing
Number of live trees ≥1,000 trees per acre
Release
Basal area of live saplings ≤70 percent of basal area of all live trees
Basal area of all live trees <80 sq. ft./acre
Do nothing
Basal area of all live trees ≥80 sq. ft./acre
Basal area of live poletimber trees <20 sq. ft./acre
Basal area of live sawtimber trees <80 sq. ft./acre
Do nothing
Basal area of live sawtimber trees ≥80 sq. ft./acre
Thin sawtimber to 70 sq. ft./acre
Basal area of live poletimber trees ≥20 sq. ft./acre
Basal area of live sawtimber trees <80 sq. ft./acre
Leave sawtimber, but thin poletimber to a combined level of sawtimber and poletimber basal area of 85 sq. ft./acre
Basal area of live sawtimber trees ≥80 sq. ft./acre
Thin sawtimber to 70 sq. ft./acre, and thin poletimber to 15 sq. ft./acre

Figure 4.—*Diagram of logic used by the computer to sort plots into treatment classes for stands in the maple-birch forest type that are neither primarily yellow birch nor hemlock (stand composition 3).*

TSI or release set forth by Brand (1981). Like the thinning criteria discussed earlier, TSI and release criteria differ by forest type. These criteria employ number of trees per acre, stand basal area, and tree mean d.b.h. to select stands for TSI and release work. Poletimber stands that fit the criteria for thinning except that they would yield less than 3 cords of growing stock per acre were targeted for TSI. The remaining plots that did not meet either TSI or release criteria were scheduled for no treatment.

FINDINGS

According to our criteria, 10.9 million acres (63 percent of the commercial forest area) qualify for some kind of forest management beween 1981 and 1990. No treatment is required on 5.8 million acres (33 percent of the commercial forest) and nonstocked areas and hydric sites comprise the remaining 0.8 million acres (4 percent). Most—4.4 million acres (65 percent of the commercial area in the Unit)—of the areas that qualify for forest management treatment are in the Northern Lower Peninsula Survey Unit (fig. 5).

The average annual volume of removals from all treatments is 971 million cubic feet of growing stock. Harvest and thinning alone account for 801 million cubic feet, including 2.6 billion board feet of sawtimber. In addition, these 2 treatments yield an average of 41 million cubic feet of short-log cull and rough and rotten cull tree removals each year.

Harvest Management Opportunities

Area

Harvest represents the most extensive treatment in the State; 4.5 million acres qualify for this type of management between 1981 and 1990 (Appendix table 3). Fifty-four percent (346,000 acres) of the balsam fir forest type area qualifies for harvest, the highest proportion among types. This is due to the large area in stands over rotation age (43 percent of the balsam fir type). The greatest area in the harvest category, however, is the 1.4 million acres in the aspen type, representing 41 percent of the total area of the type. This reflects the overmature condition of much of the State's aspen—47 percent of the aspen type is over rotation age. (The difference between the 47 percent of aspen type over rotation age and the 41 percent of the type in the harvest category is the area of overmature aspen stands selected by FIASTEMS for treatments other than harvest.) Al-

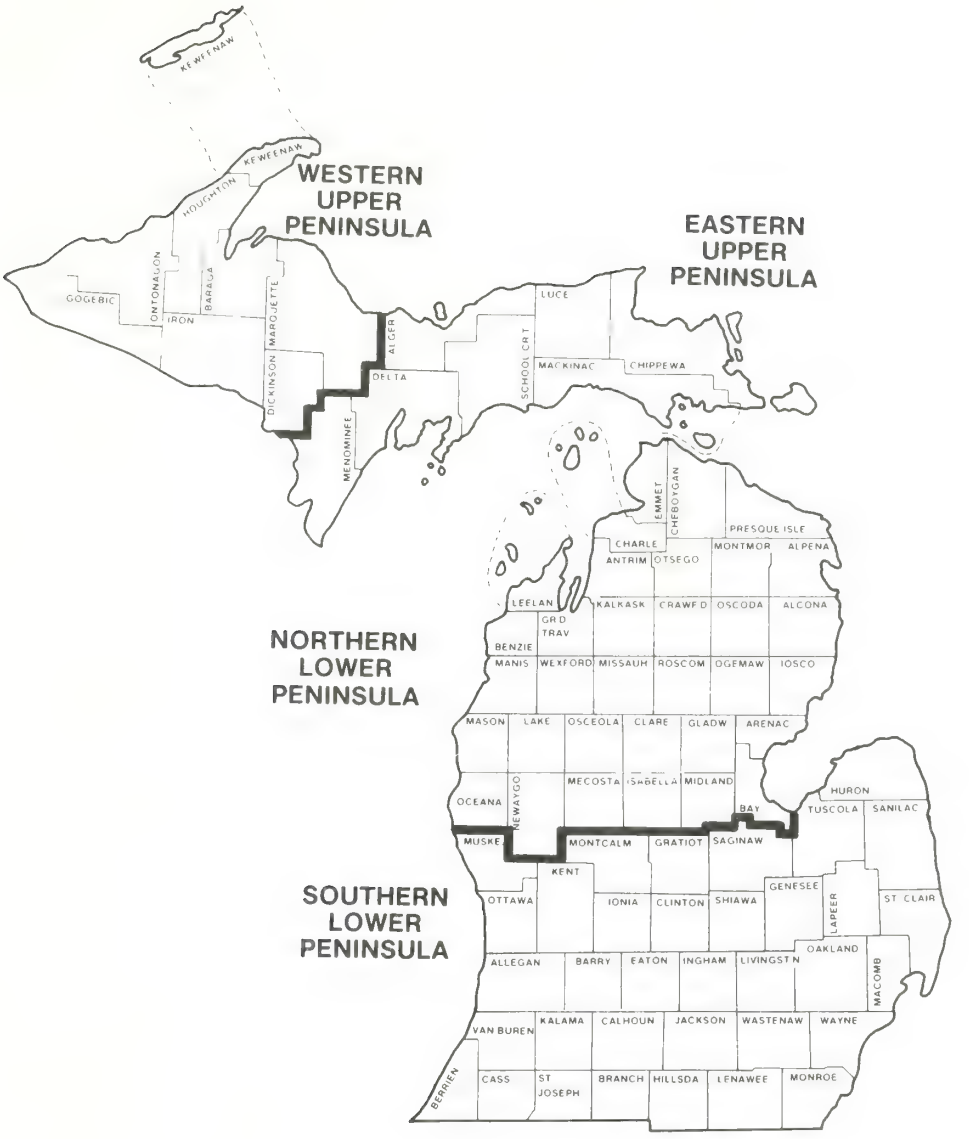

Figure 5.—*Forest Survey Units in Michigan, 1980.*

though the maple-birch type is the largest in the State (6.1 million acres—35 percent of the total commercial forest), only 481,000 acres are identified for harvesting. As mentioned earlier, selective cutting is practiced widely in the maple-birch type, is not considered the final cut in a stand, and is therefore classed under thinning.

Nonindustrial privately owned forest land accounts for 56 percent of the area that qualifies for harvest (roughly equal to the 53 percent of the total commercial forest land held by these owners). Eighty-one percent of the harvest area is in stands more than 50 years old, and 28 percent is in stands more than 90 years old. Much of the area identified for harvest is in small stands—58 percent of the harvest area is in stands less than 20 acres in size. But 12 percent of the harvest area is in stands 160 acres in size and larger.

Volume

The average annual volume of timber removals on the above harvested acres between 1981 and 1990 would be 725 million cubic feet in live trees, of which 690 million is in growing-stock trees. Sawtimber removals would be 2.4 billion board feet annually. Softwoods account for 36 percent of the growing-stock harvest removals volume (245 million cubic feet), although softwoods comprise only 28 percent of the State's growing-stock inventory. The aspens contribute the largest removals volume (152 million cubic feet), followed by soft maple (74 million) and northern white-cedar (72 million). Although aspens represent only 14 percent of the total growing-stock inventory, their removals represent 22 percent of the total volume of removals from harvest. This further reflects the overmature condition of much of the State's aspen.

Forty percent of the growing-stock removals from harvest management opportunities (275 million cubic feet) would come from stands older than 80 years, and 66 percent of it (457 million cubic feet) would come from stands greater than 60 years of age. An average of 1,545 cubic feet of growing stock, including 5,436 board feet of sawtimber, would be removed for each acre identified for harvest. As shown below, annual growing-stock removals per acre would be highest in the red pine type, but sawtimber removals per acre would be greatest in the white pine type:

Forest type	Average harvest volume per acre	
	Growing stock (Cubic feet)	Sawtimber (Board feet)[7]
Red pine	1,962	8,776
White spruce	1,949	6,862
White pine	1,926	8,944
Paper birch	1,759	4,457
Aspen	1,710	5,866
Oak-hickory	1,702	7,715
Northern white-cedar	1,671	4,410
Elm-ash-soft maple	1,634	6,601
Balsam fir	1,579	4,835
Exotic	1,501	5,138
Black spruce	1,305	2,935
Jack pine	1,201	3,507
Tamarack	918	1,712
Maple-birch	723	2,777
Average for all types	1,545	5,436

Thinning Management Opportunities

Area

Thinning is the identified treatment on 1.7 million acres during the decade. About 84 percent (1.4 million acres) of the thinning would be in the maple-birch forest type. As mentioned earlier, selection cuts in the maple-birch type are considered thinnings. The bulk of the thinning area is in the Northern Lower Peninsula Survey Unit (39 percent) and the Western Upper Peninsula Unit (32 percent). Fifty-two percent of the stands that qualify for thinning (880,000 acres) are owned by nonindustrial private parties, virtually the same as the proportion they own of the total commercial forest (53 percent). National Forest land accounts for 19 percent of the thinning acres but for only 14 percent of the commercial area. And State land comprises just 14 percent of the area that qualifies for thinning even though it makes up 20 percent of the commercial forest.

Sixty-three percent of the thinning area is in stands 60 years of age or younger. The remaining 37 percent is entirely within the maple-birch type and represents stands that would be selectively cut.

Volume

Annual removals of 117 million cubic feet of all live trees would result from thinning the above area. Growing-stock removals amount to 111 million cubic feet of it; the remaining 6 million cubic feet would be from short-log, rough, and rotten cull trees. Sixty-three percent of the growing-stock removals are in poletimber-size trees. More than half of the removals volume from thinnings is in hard maple (36 million cubic feet) and soft maple (24 million cubic feet), followed by red pine (11 million), the aspens (6 million), and basswood (5 million). Almost all of the hard and soft maple removals volume is in the maple-birch type.

An average of 663 cubic feet of growing stock would be removed for every acre thinned during the decade. Removals per acre are highest in the white and red pine forest types as shown below:

Forest type	Average volume of thinnings per acre (Cubic feet)
White pine	1,152
Red pine	1,073
White spruce	809
Maple-birch	634
Oak-hickory	594
All types	663

Timber Stand Improvement Management Opportunities

Timber stand improvement (TSI) is the identified treatment on 1.2 million acres. Ninety-four percent of this area is in the maple-birch forest type; the rest is mostly in the oak-hickory type. Forest industry and farmer-owned forest land bears a proportionally greater share of the TSI area than their areas of the total commercial forest. For example, forest industry and farmer-owned forest represent 16 and 26 percent, respectively, of the area selected for TSI. However, they comprise only 11 and 18 percent, respectively, of the commercial forest area. National Forests and State-owned forests display the opposite—proportionally smaller areas of TSI than of the total forest.

TSI was identified for stands of all ages except the 141 year and over age class as shown in the following tabulation (stands in the older age classes are those in the maple-birch forest type that would have been

[7] *International 1/4-inch rule.*

scheduled for thinning had they yielded 3 cords or more per acre):

Stand-age class (Years)	Area of commercial forest land (Thousand acres)
1-10	64.8
11-20	61.4
21-30	74.1
31-40	148.7
41-50	268.4
51-60	212.8
61-70	110.5
71-80	75.8
81-90	68.4
91-100	71.6
101-120	72.5
121-140	12.0
141 +	--
All classes	1,241.0

Fifty-seven percent of stands targeted for TSI are less than 20 acres in size, and 73 percent of them are less than 40 acres in size.

Annual removals of 7 million cubic feet of growing stock would result from TSI work.

Release Management Opportunities

Release is specified on 514,000 acres or 5 percent of the total area for all treatments. Eighty-two percent of the release area is in three forest types—jack pine (208,000 acres), northern white-cedar (116,000), and balsam fir (100,000). The greatest area of release is targeted for State-owned forest (150,000 acres) and National Forest land (131,000). These two owners together account for 54 percent of the release area but for only 34 percent of the total commercial forest. Fifty-six percent of the release area is in stands less than 10 acres in size.

Release would yield annual removals of 6 million cubic feet of growing stock.

Restocking Management Opportunities

Inadequate stocking is seen as a problem on 570,000 acres, or 5 percent of the area to be treated. Every forest type except the paper birch type is scheduled to be restocked. As mentioned earlier, the current practice in the "swamp conifer" and aspen types is to perform no regeneration work. Area in these types classed under the restocking management opportunity, therefore, represent a reservoir of inadequately stocked acres on which growth and yield could be substantially increased if stocking were improved. The maple-birch and aspen types, each with 118,000 acres scheduled for restocking, together lead all other types with 41 percent of the area to be restocked. Nonindustrial private owners are targeted for a larger proportional share of restocking than other owners—although they own 53 percent of the commercial forest, their land represents 63 percent of the area that requires restocking. Two-thirds of the area scheduled for restocking is in stands less than 10 acres in size.

Stand Conversion Management Opportunities

Stand conversion, with a scheduled 2.4 million acres, is the second most extensive treatment. Only four forest types are seen as prospects for stand conversion—maple-birch leads all others (42 percent of the area to be so-treated), followed by aspen (28 percent), oak-hickory (22 percent), and paper birch (8 percent). Ninety-one percent of the area to be converted is on sites capable of growing less than 50 cubic feet per acre per year (the lowest site class) with the existing forest type. If the stands were converted to other types better suited to the site conditions, the timber growth capability in most new stands would be raised. Conversion of forest industry land would be proportionally greater than for other owners. Fifteen percent of the scheduled stand conversion is on forest industry land, but only 11 percent of the commercial forest is forest industry-owned. Forty-two percent of the area to be converted is in stands less than 10 acres in size, and 62 percent of it is in stands less than 20 acres.

Annual growing-stock removals of 157 million cubic feet are estimated from sites identified for stand conversion.

Land Not Scheduled For Management

No Treatment

A total of 5.8 million acres, one-third of the commercial forest area in Michigan, is not scheduled for any treatment. This area includes stands that are adequately stocked and less than harvest age, as well as those that do not meet the criteria for timber stand improvement, thinning or release. Essentially, they are stands that would not benefit biologically from the intervention of man during the next decade.

Hydric Sites

Very wet sites comprise 587,000 acres of commercial forest land. These sites are difficult to manage because they are often inaccessible, except during winter, and because the species growing on these sites grow slowly. Fifty-eight percent of the area of commercial forest land on hydric sites is in the three "swamp conifer" types—northern white-cedar (150,000 acres), black spruce (144,000), and tama-

rack (48,000). Fifty-five percent of the area of hydric sites is in stands less than 10 acres in size.

Nonstocked Areas

Only 172,000 acres of commercial forest land are nonstocked with trees. Some of these areas may not be artificially regenerated to trees because they are too small or have low site productivity. Given the right conditions and time—perhaps much longer than the 10-year period discussed here—many will regenerate naturally. Those that are artificially regenerated will need to be considered independently before planting or seeding to estimate the probable economic and silvicultural success of such action.

DISCUSSION

According to the criteria used in this analysis, 10.9 million acres of the 17.5 million acres of commercial forest land in the State would benefit from some kind of forest management between 1981 and 1990. These criteria, discussed earlier, address only biological considerations. Economic, social, or political constraints to the undertaking of such work are not considered. The estimates shown for each treatment class are biological maximums, given current stand conditions in the State and the treatment criteria used. This is one reason that all 10.9 million acres may not be treated as described earlier. Other reasons are the lack of markets for all the forest products and species removed during treatment, the small area of many stands identified for treatment, some private landowners' present commitment to manage the land for nontimber use, inability of some landowners to afford the cost of some treatments where the sale of timber products is not anticipated to help defray costs, and inaccessibility of some land. The reader should use his or her knowledge of local resource conditions to discount the treatment estimates.

No treatment is suggested for 5.8 million acres of commercial forest. Hydric sites and nonstocked areas comprise the remaining 0.8 million acres of the commercial area.

As shown below, the most widely applied treatment between 1981 and 1990 would be harvest:

Treatment	Area (Thousand acres)	Annual growing-stock removals (Million cubic feet)
Harvest	4,462	690
Stand conversion	2,438	157
Thinning	1,678	111
Timber stand improvement	1,241	7
Restocking	570	([8])
Release	514	6
All treatments	10,903	971

The average annual yield from this harvest is estimated at 690 million cubic feet of growing stock. Thinning, the other treatment most likely to be performed, is seen as a benefit to 1.7 million acres during the decade. Thinning would yield an additional 111 million cubic feet of growing stock annually. These two treatments alone would generate the annual removal of 801 million cubic feet of growing stock.

The large area qualifying for harvest is a measure of the extent of stands over rotation age in some forest types, particularly the aspen and balsam fir types. Some types can remain healthy for decades after passing rotation age, although the growth rates may drop precipitously. However, aspen stands, especially those on low sites, tend to deteriorate or "break up" quickly after reaching this age. Unless harvested very soon thereafter, they will provide little or no commercially valuable fiber. Of the 3.4 million acres in the aspen type in the State, 1.6 million acres are over rotation age (40 years).

An impediment to harvest is that 2.6 million acres of the 4.5 million acres qualifying for this treatment are in stands less than 20 acres in area. Timber operators may consider some of these areas economically unattractive to log unless they are close to other areas to be harvested or support exceptionally large volumes per acre and/or valuable species.

The area and associated volumes of the harvest treatment are slightly understated and the area and associated volumes of the thinning treatment are slightly overstated because tree selection cuts in the maple-birch type are included under thinning.

Stand conversion of the 2.4 million acres identified for this treatment would yield average annual removals of 157 million cubic feet between 1981 and 1990. Twenty-four percent of the conversion area is in stands from 1 to 4 acres in size. Another 18 percent is in stands from 5 to 9 acres in size. These small areas lessen the chances of such stands being treated. Although the size of timber cleared from converted sites may be small and the quality of such trees low, this timber is particularly well suited to whole-tree chipping to produce pulp chips or boiler fuel.

Timber stand improvement on the 1.2 million acres selected would produce 7 million cubic feet of growing-stock removals annually during the decade. Most of the material cut would be too small to be utilized for most roundwood products, but it could be

[8] *An estimated 17 million cubic feet of growing stock occurs on sites identified for restocking, but little of this is likely to be removed.*

used for fuelwood or be whole-tree chipped. Thirty-four percent of the TSI area is in stands less than 10 acres in size, thereby diminishing the likelihood that all these stands will be located and treated.

Annual removals of 6 million cubic feet of growing stock would be generated by release work done on the 0.5 million acres identified for this treatment. Many of the trees to be removed have large diameters, although they may not be of desirable species. Fifty-six percent of the stands qualifying for release are less than 10 acres in size, therefore, many of them probably will not be treated.

Of the 570,000 acres cited for restocking 161,000 acres are in either "swamp conifer" or aspen types where artificial regeneration is not usually practiced. However, the 161,000 acres represents an opportunity to expand the growth and yield in stands where this is not likely to happen without man's intervention. The balance of 409,000 acres in this treatment opportunity is most likely to be restocked.

In addition to the above restocking acres, part of the 172,000 acres of nonstocked commercial forest could also be planted or seeded to trees. Other nonstocked areas may be poor planting chances because of shallow, rocky soil or inadequate soil drainage. Nonstocked areas would have to be inspected on-the-ground to accurately determine which ones represent economically viable opportunities for regeneration.

Stand conversion, timber stand improvement, release, and restocking may be performed less intensively than harvest and thinning for a number of reasons. But these treatments would do much to shift marginally producing commercial forest land closer to its timber-producing potential. At least some of the timber cut from these stands could be sold to help defray the treatment cost. Markets that can utilize chips or small, irregular length, low quality logs, such as for pallet or crate construction, are particularly attractive.

A comparison of the average annual growing-stock removals that would be generated from all forest management opportunities with actual removals for 1979 shows a large difference between the two (table 2).

Average annual removals from all management opportunities (971 million cubic feet) are 3 1/2 times greater than actual removals in 1979 (275 million cubic feet). If only average annual removals from harvest and thinning opportunities are considered, the 801 million cubic feet are still almost three times greater than 1979 removals. The above removals volumes are only for growing-stock trees. If biomass or whole-tree utilization were performed, these volumes could be substantially increased, especially in the aspen type. *The yields from forest management opportunities could not be sustained beyond 1990* and are to be interpreted only as the annual volume that could be removed between 1981 and 1990 if all the treatments were performed. If the treatments are not performed, inventory volumes would still accumulate in the State because growth volumes are projected to exceed removals volumes beyond 1990.

The sustained yield for Michigan from harvest, thinning, and TSI treatments on stocked stands was estimated to fall between 466 and 725 million cubic feet.[9] This estimate was based on an area control technique. Sustainable volumes for the harvest portion alone for growing stock were generated from empirical yield estimates from stands currently at rotation age (373 million cubic feet annually), representing minimal management, and from published yield tables for well-stocked stands (580 million cubic feet), representing more intensive management.

The disparity between average annual removals resulting from all management opportunities between 1981 and 1990 and the 1979 removals would be much greater for softwoods than for hardwoods. Average softwood removals between 1981 and 1990 would be 5.4 times the 1979 softwood removals, compared to 3.0 times for hardwood removals. If only the average annual removals from harvest and thinning are considered, the same numbers are 4.7 times for softwoods and 2.4 times for hardwoods. Among softwood species, northern white-cedar and balsam fir would be harvested at rates elevated the highest above those of 1979.

The treatments discussed in this paper are limited to those on commercial forest land. Opportunities also exist for forest management on wooded strips (241,000 acres), windbreaks (37,000 acres), idle farmland (13,000 acres), and wooded pasture (13,000 acres), all of which are in the nonforest with trees land class.

Landowners desiring assistance in managing their forest land may contact the Michigan (DNR) Cooperative Forest Management Specialist at their local district DNR office. Locations of these district offices are available at the Michigan DNR, Division of Forest Management, Box 30028, Lansing, Michigan 48909, phone: (517) 373-1275. Landowners may also wish to contact forestry consultants and/or forest industry professionals for forest management assistance.

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[9]*Jakes, Pamela J.; Smith, W. Brad. Michigan's predicted timber yields 1981-2010. Res. Pap. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1983. 98 p.*

Table 2.--Comparison of average annual growing-stock removals on commercial forest land from forest management opportunities, Michigan, 1981-1990, and actual growing-stock removals estimated for 1979.

(In Million cubic feet)

Item	Total	Softwoods	Hardwoods
Average annual removals, 1981-1990 that would result from:			
Harvest and thinning	800.9	266.5	534.4
All other management opportunities	170.3	40.0	130.3
All opportunities	971.2	306.5	664.7
1979 removals	274.6	56.4	218.2
Difference	696.6	250.1	446.5

APPENDIX

TREE SPECIES GROUPS IN MICHIGAN[10]

Softwoods
- Eastern white pine ..... *Pinus strobus*
- Red pine ..... *Pinus resinosa*
- Jack pine ..... *Pinus banksiana*
- White spruce ..... *Picea glauca*
- Black spruce ..... *Picea mariana*
- Balsam fir ..... *Abies balsamea*
- Eastern hemlock ..... *Tsuga canadensis*
- Tamarack ..... *Larix laricina*
- Northern white-cedar ..... *Thuja occidentalis*
- Other softwoods
  - Eastern redcedar ..... *Juniperus virginiana*
  - Norway spruce ..... *Picea abies*
  - Engelmann spruce ..... *Picea engelmannii*
  - Austrian pine ..... *Pinus nigra*
  - Scotch pine ..... *Pinus sylvestris*

Hardwoods
- White oaks
  - White oak ..... *Quercus alba*
  - Swamp white oak ..... *Quercus bicolor*
  - Bur oak ..... *Quercus macrocarpa*
  - Chinkapin oak ..... *Quercus muehlenbergii*
  - Chestnut oak ..... *Quercus prinus*
- Select red oak
  - Northern red oak ..... *Quercus rubra*
- Other red oaks
  - Scarlet oak ..... *Quercus coccinea*
  - Northern pin oak ..... *Quercus ellipsoidalis*
  - Pin oak ..... *Quercus palustris*
  - Black oak ..... *Quercus velutina*
- Hickories
  - Bitternut hickory ..... *Carya cordiformis*
  - Pignut hickory ..... *Carya glabra*
  - Shellbark hickory ..... *Carya laciniosa*
  - Shagbark hickory ..... *Carya ovata*
  - Mockernut hickory ..... *Carya tomentosa*
- Yellow birch ..... *Betula alleghaniensis*
- Hard maples
  - Sugar maple ..... *Acer saccharum*
  - Black maple ..... *Acer nigrum*
- Soft maples
  - Red maple ..... *Acer rubrum*
  - Silver maple ..... *Acer saccharinum*
- American beech ..... *Fagus grandifolia*
- Ashes
  - White ash ..... *Fraxinus americana*
  - Black ash ..... *Fraxinus nigra*
  - Green ash ..... *Fraxinus pennsylvanica*
- Balsam poplar ..... *Populus balsamifera*
- Eastern cottonwood ..... *Populus deltoides*
- Aspens
  - Bigtooth aspen ..... *Populus grandidentata*
  - Quaking aspen ..... *Populus tremuloides*
- American basswood ..... *Tilia americana*
- Yellow-poplar ..... *Liriodendron tulipifera*
- Black walnut ..... *Juglans nigra*
- Black cherry ..... *Prunus serotina*
- Butternut ..... *Juglans cinerea*
- Elms
  - American elm ..... *Ulmus americana*
  - Slippery elm ..... *Ulmus rubra*
  - Rock elm ..... *Ulmus thomasii*
- Paper birch ..... *Betula papyrifera*
- River birch ..... *Betula nigra*
- Black willow ..... *Salix nigra*
- Sycamore ..... *Platanus occidentalis*
- Other hardwoods
  - Boxelder ..... *Acer negundo*
  - Sweet birch ..... *Betula lenta*
  - Ohio buckeye ..... *Aesculus glabra*
  - Flowering dogwood ..... *Cornus florida*
  - Honeylocust ..... *Gleditsia triacanthos*
  - Osage orange ..... *Maclura pomifera*
  - Black tupelo .. *Nyssa sylvatica var. sylvatica*
  - Black locust ..... *Robinia pseudoacacia*
  - Sassafras ..... *Sassafras albidum*
  - Red mulberry ..... *Morus rubra*
  - American chestnut ..... *Castanea dentata*

[10] *The common and scientific names are based on, Little, Elbert L., Jr. Checklist of United States trees (native and naturalized). Agric. Handbk. 541. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 375 p.*

METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.
1 pound = 0.454 kilogram.
1 ton = 0.907 metric ton.

DEFINITION OF TERMS

Basal area.—The area in square feet of the cross section at breast height of a single tree. When the basal area of all trees in a stand are summed, the result is usually expressed as square feet of basal area per acre.

Commercial forest land.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of annual growth under

management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.) Also see definition of pastured commercial forest land.

Commercial species.—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

County and municipal land.—Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

Cropland.—Land under cultivation within the past 24 months, including cropland harvested, crop failures, cultivated summer fallow, idle cropland used only for pasture, orchards, and land in soil improved crops, but excluding land cultivated in developing improved pasture.

Cull.—Portions of a tree that are unusable for industrial wood products, because of rot, form, or other defect.

Diameter classes.—A classification of trees based on diameter outside bark, measured at breast height (4½ feet above the ground). (Note: d.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Survey, with the even inch the approximate midpoint for a class. For example, the 6-inch class includes trees 5.0 through 6.9 inches d.b.h. inclusive).

Farm.—Any land from which $1,000 or more of agricultural products were grown and sold or normally would have been sold during the year.

Farmer-owned land.—Land owned by farm operators. (Note: Excludes land leased by farm operators from nonfarm owners, such as railroad companies and States.)

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note: Stocking is measured by comparison of basal area and/or number of trees, by age or size and spacing with specified standards.) The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas shall be classed as forest if less than 120 feet wide. Also see definitions for land area, commercial forest land, noncommercial forest land, productive-reserved forest land, stocking, unproductive forest land, and water.

Forest industry land.—Land owned by companies or individuals operating primary wood-using plants.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet in height at maturity.

Forest type.—A classification of forest land based upon the species forming a plurality of live tree stocking. Major forest types in Michigan are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of the stocking with balsam fir the most common. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include balsam fir, aspen, maple, birch, northern white-cedar, and tamarack.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. (Common associates include jack pine, beech, yellow-poplar, elm, and maple.)

Elm-ash-soft maple.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

Maple-birch.—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a

plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Exotic.—Forests in which species not native to Michigan comprise a plurality of the stocking. (Mostly scotch pine plantations.)

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to standard cords by dividing by 79. One standard cord is 128 cubic feet of stacked wood, including bark and air.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Indian land.—All lands held in trust by the United States for individual Indians or tribes, or all lands, titles to which are held by individual Indians or tribes, subject to Federal restrictions against alienation.

Industrial wood.—All roundwood products, except fuelwood.

Land area.—A. *Bureau of the Census*.—The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs, estuaries, and canals less than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

B. *Forest Inventory and Analysis*. The same as the Bureau of the Census, except minimum width of streams, etc. is 120 feet and minimum size of lakes, etc. is 1 acre.

Live trees.—Growing-stock, rough and rotten trees 1 inch d.b.h. and larger.

Log grades.—A classification of logs based on external characteristics as indicators of quality or value. (See Appendix for specific grading factors used.)

Logging residues.—The unused growing-stock portions of trees cut or killed by logging.

Merchantable.—Refers to a pulpwood or saw log section that meets pulpwood or saw log specifications, respectively.

Miscellaneous federal land.—Federal land other than National Forest and land administered by the Bureau of Land Management.

Miscellaneous private land.—Privately owned land other than forest-industry and farmer-owned land.

Mortality.—The volume of sound wood in growing-stock and sawtimber trees that die annually.

National Forest land.—Federal land that has been legally designated as National Forest or purchase units, and other land under the administration of the USDA Forest Service.

Net annual growth of growing stock.—The annual change in volume of sound wood in live sawtimber and poletimber trees and the total volume of trees entering these classes through ingrowth, less volume losses resulting from natural causes.

Net annual growth of sawtimber.—The annual change in the volume of live sawtimber trees and the total volume of trees reaching sawtimber size, less volume losses resulting from natural causes.

Net volume.—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Noncommercial forest land.—(a) Unproductive forest land and (b) productive-reserved forest land.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality which normally do not develop into trees suitable for industrial wood products.

Nonforest land.—Land that has never supported forests, and land formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide and more than 1 acre in area, to qualify as nonforest land.)

a. *Nonforest land without trees*.—Nonforest land with no live trees present.

b. *Nonforest land with trees*.—Nonforest land with one or more trees per acre at least 5 inches d.b.h.

Nonstocked land.—Commercial forest land less than 16.7 percent stocked with growing-stock trees.

Other removals.—Growing-stock trees removed but not utilized for products, or trees left standing but "removed" from the commercial forest land classification by land use change. Examples are removals from cultural operations such as timber stand improvement work, land clearing, and changes in land use.

Ownership.—Property owned by one owner, regardless of the number of parcels in a specified area.

Ownership size class.—The amount of commercial forest land owned by one owner, regardless of the number or parcels.

Poletimber stands.—(See stand-size class.)

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches d.b.h., but smaller than sawtimber size.

Productive-reserved forest land.—Forest land sufficiently productive to qualify as commercial forest land but withdrawn from timber utilization through statute, administrative regulation, designation, or exclusive use for Christmas tree production, as indicated by annual shearing.

Rotten trees.—Live trees of commercial species that do not contain at least one 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume in a tree is rotten.

Rough trees.—(a) Live trees of commercial species that do not contain at least one merchantable 12-foot saw log or two saw logs 8 feet or longer, now or prospectively, and/or do not meet Regional specifications for freedom from defect primarily because of roughness or poor form, and (b) all live trees of noncommercial species.

Roundwood products.—Logs, bolts, or other round sections (including chips from roundwood) cut from trees for industrial or consumer uses. (Note: Includes saw logs, veneer logs and bolts; cooperage logs and bolts; pulpwood; fuelwood; piling; poles; posts; hewn ties; mine timbers; and various other round, split, or hewn products.)

Salvable dead trees.—Standing or down dead trees that are considered merchantable by Regional standards.

Saplings.—Live trees 1- to 5-inches d.b.h.

Sapling-seedling stands.—(See stand-size class.)

Saw log.—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by Regional standards.

Saw log portion.—That part of the bole of sawtimber trees between the stump and the saw log top.

Saw log top.—The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for softwoods and 9 inches d.o.b. for hardwoods.

Sawtimber stands.—(See stand-size class.)

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting Regional specifications for freedom from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

Sawtimber volume.—Net volume of the saw log portion of live sawtimber in board feet, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Seedlings.—Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

Short-log (rough tree).—Sawtimber-size trees of commercial species that contain at least one merchantable 8- to 11-foot saw log but not a 12-foot saw log.

Site class.—A classification of forest land in terms of inherent capacity to grow crops of industrial wood based on fully stocked natural stands.

Site index.—An expression of forest site quality based on the height of a free-growing dominant or codominant tree of a representative species in the forest type at age 50.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-area class.—The extent of a continuous forested area of the same forest type, stand-size class, and stand-density class.

Stand-size class.—A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber or seedlings and saplings.

a. *Sawtimber stands*.—Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

b. *Poletimber stands*.—Stands at least 16.7 percent stocked with growing-stock trees of which half or more of this stocking is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

c. *Sapling-seedling stands*.—Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the stocking is saplings and/or seedlings.

d. *Nonstocked areas*.—Commercial forest land on which stocking of growing-stock trees is less than 16.7 percent.

State land.—Land owned by States, or land leased to these governmental units for 50 years or more.

Stocking.—The degree of occupancy of land by trees, measured by basal area and/or the number of trees in a stand by size or age and spacing, compared to the basal area and/or number of trees required to fully utilize the growth potential of the land; that is, the stocking standard.

A stocking percent of 100 indicates full utilization of the site and is equivalent to 80 square feet

of basal area per acre in trees 5 inches d.b.h. and larger. In a stand of trees less than 5 inches d.b.h., a stocking percent of 100 would indicate that the present number of trees is sufficient to produce 80 square feet of basal area per acre when the trees reach 5 inches d.b.h.

Stands are grouped into the following stocking classes:

Overstocked stands.—Stands in which stocking of trees is 134.0 percent or more.

Fully stocked stands.—Stands in which stocking of trees is from 101.0 to 133.9 percent.

Medium stocked stands.—Stands in which stocking of trees is from 61.0 to 100.9 percent.

Poorly stocked stands.—Stands in which stocking of trees is from 16.7 to 60.9 percent.

Nonstocked areas.—Commercial forest land on which stocking of trees is less than 16.7 percent.

Timber removals from growing stock.—The volume of sound wood in growing-stock trees removed annually for forest products (including roundwood products and logging residues) and for other removals.

Timber removals from sawtimber.—The net board-foot volume of live sawtimber trees removed for forest products annually (including roundwood products and logging residues) and for other removals.

Tree size class.—A classification of trees based on diameter at breast height, including sawtimber trees, poletimber trees, saplings, and seedlings.

Unproductive forest land.—Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soils, dry climate, poor drainage, high elevation, steepness, and rockiness.

Upper stem portion.—That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Water.—(a) *Bureau of the Census*.—Streams, sloughs, estuaries, and canals more than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds more than 40 acres in area.

(b) *Noncensus*.—The same as the Bureau of the Census, except minimum width of streams, etc. is 120 feet and minimum size of lakes, etc. is 1 acre.

Wooded pasture.—Improved pasture with more than 16.7 percent stocking in live trees but less than 25 percent stocking in growing-stock trees. Area is currently improved for grazing or there is other evidence of grazing.

Wooded strip.—An acre or more of natural continuous forest land that would otherwise meet survey standards for commercial forest land except that it is less than 120 feet wide.

TABLES

Table 1.—Management criteria, 1981-1990

Table 2.—Comparison of average annual growing-stock removals on commercial forest land from forest management opportunities, 1981-1990, and actual growing-stock removals estimated for 1979

Table 3.—Area of commercial forest land qualifying for management by forest type, treatment, and Forest Survey Unit, 1981-1990

Table 4.—Area of commercial forest land by forest type, site class, and treatment, 1981-1990

Table 5.—Area of commercial forest land by ownership class, site class, and treatment, 1981-1990

Table 6.—Area of commercial forest land by treatment and stand-area class, 1981-1990

Table 7.—Area of commercial forest land qualifying for harvest by forest type and stand-age class, 1981-1990

Table 8.—Area of commercial forest land qualifying for thinning by forest type and stand-age class, 1981-1990

Table 9.—Average annual growing-stock and sawtimber removals on commercial forest land qualifying for harvest by species group and tree class, 1981-1990

Table 10.—Average annual growing-stock and sawtimber removals on commercial forest land qualifying for thinning by species group and tree class, 1981-1990

Table 11.—Average annual growing-stock removals on commercial forest land qualifying for harvest by species group and forest type, 1981-1990

Table 12.—Average annual growing-stock removals on commercial forest land qualifying for thinning by species group and forest type, 1981-1990

Table 13.—Average annual sawtimber removals on commercial forest land qualifying for harvest by species group and forest type, 1981-1990

Table 14.—Average annual growing-stock removals on commercial forest land qualifying for harvest by forest type and stand-age class, 1981-1990

Table 15.—Average annual growing-stock removals on commercial forest land qualifying for thinning by forest type and stand-age class, 1981-1990

Table 16.—Average annual growing-stock removals per acre on commercial forest land qualifying for harvest by forest type and stand-age class, 1981-1990

Table 17.—Average annual growing-stock removals per acre on commercial forest land qualifying for thinning by forest type and stand-age class, 1981-1990

Table 3.--Area of commercial forest land qualifying for management by forest type, treatment, and Forest Survey Unit, Michigan, 1981-1990

(In thousand acres)

ALL UNITS

Forest type	All commercial forest land	Treatment						Untreated		
		Harvest	Thinning	Timber stand improvement	Release	Restocking	Stand conversion	Nonstocked	Hydric sites	No treatment
Jack pine	836.7	337.1	--	--	207.8	75.4	--	--	4.1	212.3
Red pine	655.9	90.3	121.7	1.7	--	36.2	--	--	1.7	404.5
White pine	214.1	86.9	7.5	--	44.2	16.9	--	--	5.4	53.2
Balsam fir	635.4	345.7	--	--	100.1	17.9	--	--	39.6	132.1
White spruce	106.1	34.4	4.4	--	30.0	7.8	--	--	1.4	22.1
Black spruce	520.6	59.5	--	--	--	16.7[1/]	--	--	144.2	300.2
Northern white-cedar	1,173.6	490.4	--	--	116.0	19.0[1/]	--	--	150.2	398.0
Tamarack	114.8	22.3	--	--	--	7.4[1/]	--	--	47.6	37.5
Oak-hickory	1,773.6	547.1	141.5	68.3	--	38.7	534.3	--	--	443.7
Elm-ash-soft maple	1,326.4	426.1	--	--	--	95.2	--	--	127.4	677.7
Maple-birch	6,098.4	481.0	1,407.5	1,171.0	16.4	117.7	1,029.9	--	15.4	1,859.5
Aspen	3,406.6	1,403.7	--	--	--	117.8[1/]	683.8	--	43.6	1,157.7
Paper birch	374.8	128.5	--	--	--	--	189.6	--	5.9	50.8
Exotic	86.3	9.3	--	--	--	3.5	--	--	--	73.5
Nonstocked	172.2	--	--	--	--	--	--	172.2	--	--
All types	17,489.5	4,462.3	1,677.6	1,241.0	514.5	570.2	2,437.6	172.2	586.5	5,827.6
EASTERN UPPER PENINSULA										
Jack pine	229.1	98.3	--	--	41.7	30.1	--	--	0.7	58.3
Red pine	139.8	21.8	14.3	--	--	9.0	--	--	1.7	93.0
White pine	68.7	26.6	--	--	9.3	6.3	--	--	1.5	25.0
Balsam fir	217.4	101.6	--	--	37.4	2.7	--	--	7.9	67.8
White spruce	30.1	10.4	4.4	--	2.7	4.8	--	--	--	7.8
Black spruce	283.1	19.5	--	--	--	8.6[1/]	--	--	62.3	192.7
Northern white-cedar	594.9	218.5	--	--	49.7	8.3[1/]	--	--	79.0	239.4
Tamarack	43.8	14.5	--	--	--	4.4[1/]	--	--	11.2	13.7
Oak-hickory	19.3	3.1	1.9	1.5	--	1.6	2.0	--	--	9.2
Elm-ash-soft maple	191.8	70.9	--	--	--	7.3	--	--	8.9	104.7
Maple-birch	1,160.3	60.1	293.8	203.1	--	8.6	259.0	--	1.4	334.3
Aspen	671.4	243.4	--	--	--	20.4[1/]	210.5	--	27.7	169.4
Paper birch	110.5	31.4	--	--	--	--	61.5	--	4.6	13.0
Exotic	1.2	--	--	--	--	--	--	--	--	1.2
Nonstocked	40.2	--	--	--	--	--	--	40.2	--	--
All types	3,801.6	920.1	314.4	204.6	140.8	112.1	533.0	40.2	206.9	1,329.5
WESTERN UPPER PENINSULA										
Jack pine	88.3	58.5	--	--	6.3	2.9	--	--	1.6	19.0
Red pine	57.6	21.9	3.0	--	--	--	--	--	--	32.7
White pine	48.7	26.0	--	--	3.2	1.7	--	--	--	17.8
Balsam fir	366.6	209.7	--	--	53.2	13.5	--	--	30.5	59.7
White spruce	40.6	16.8	--	--	12.4	--	--	--	1.4	10.0
Black spruce	209.5	35.0	--	--	--	4.3[1/]	--	--	73.7	96.5
Northern white-cedar	210.2	112.1	--	--	8.3	--	--	--	25.9	63.9
Tamarack	36.0	1.3	--	--	--	1.2[1/]	--	--	20.7	12.8
Oak-hickory	22.6	6.4	3.2	--	--	--	8.0	--	--	5.0
Elm-ash-soft maple	169.7	84.6	--	--	--	3.4	--	--	7.8	73.9
Maple-birch	2,372.4	227.5	534.2	372.4	3.2	1.3	482.4	--	2.3	748.5
Aspen	733.3	373.2	--	--	--	20.8[1/]	130.8	--	3.3	205.2
Paper birch	143.8	60.8	--	--	--	--	65.3	--	1.3	16.4
Exotic	1.6	--	--	--	--	--	--	--	--	1.6	
Nonstocked	28.7	--	--	--	--	--	--	28.7	--	--
All types	4,529.6	1,233.8	541.0	372.4	86.6	49.1	686.5	28.7	168.5	1,363.0

(Table 3 continued on next page)

[1/] Artificial regeneration is not usually practiced in this type.

(Table 3 continued)

NORTHERN LOWER PENINSULA

Forest type	All commercial forest land	Treatment						Untreated		
		Harvest	Thinning	Timber stand improvement	Release	Restocking	Stand conversion	Nonstocked	Hydric sites	No treatment
Jack pine	506.7	172.8	--	--	159.8	42.4	--	--	1.8	129.9
Red pine	427.0	46.6	97.8	1.7	--	27.2	--	--	--	253.7
White pine	75.2	34.3	2.5	--	23.4	4.0	--	--	3.9	7.1
Balsam fir	51.4	34.4	--	--	9.5	1.7	--	--	1.2	4.6
White spruce	21.9	7.2	--	--	7.4	3.0	--	--	--	4.3
Black spruce	28.0	5.0	--	--	--	3.8[1/]	--	--	8.2	11.0
Northern white-cedar	355.5	159.6	--	--	58.0	4.5[1/]	--	--	45.3	88.1
Tamarack	30.6	6.5	--	--	--	1.8[1/]	--	--	15.7	6.6
Oak-hickory	1,068.1	208.8	88.0	38.5	--	16.9	444.0	--	--	271.9
Elm-ash-soft maple	416.3	126.7	--	--	--	37.3	--	--	41.9	210.4
Maple-birch	1,662.4	122.4	470.1	395.1	2.6	46.1	231.5	--	7.6	387.0
Aspen	1,817.5	731.1	--	--	--	66.3[1/]	317.3	--	12.6	690.2
Paper birch	113.9	36.3	--	--	--	--	59.5	--	--	18.1
Exotic	57.2	4.5	--	--	--	3.5	--	--	--	49.2
Nonstocked	63.2	--	--	--	--	--	--	63.2	--	--
All types	6,694.9	1,696.2	658.4	435.3	260.7	258.5	1,052.3	63.2	138.2	2,132.1

SOUTHERN LOWER PENINSULA

Jack pine	12.6	7.5	--	--	--	--	--	--	--	5.1
Red pine	31.5	--	6.6	--	--	--	--	--	--	24.9
White pine	21.5	--	--	--	8.3	4.9	--	--	--	8.3
Balsam fir	--	--	--	--	--	--	--	--	--	--
White spruce	7.5	--	--	--	7.5	--	--	--	--	--
Black spruce	--	--	--	--	--	--	--	--	--	--
Northern white-cedar	13.0	0.2	--	--	--	6.2[1/]	--	--	--	6.6
Tamarack	4.4	--	--	--	--	--	--	--	--	4.4
Oak-hickory	663.6	328.8	48.4	28.3	--	20.2	80.3	--	--	157.6
Elm-ash-soft maple	548.6	143.9	--	--	--	47.2	--	--	66.8	288.7
Maple-birch	903.3	71.0	108.8	200.4	10.6	61.7	57.0	--	4.1	389.7
Aspen	184.4	56.0	--	--	--	10.3[1/]	25.2	--	--	92.9
Paper birch	6.6	--	--	--	--	--	3.3	--	--	3.3
Exotic	26.3	4.8	--	--	--	--	--	--	--	21.5
Nonstocked	40.1	--	--	--	--	--	--	40.1	--	--
All types	2,463.4	612.2	163.8	228.7	26.4	150.5	165.8	40.1	72.9	1,003.0

[1/] Artificial regeneration is not usually practiced in this type.

Table 4.--Area of commercial forest land by forest type, site class, and treatment, Michigan, 1981-1990

(In thousand acres)

Forest type	All classes	Site class					
		225+	165-224	120-164	85-119	50-84	20-49
HARVEST							
Jack pine	337.1	--	--	--	14.2	92.1	230.8
Red pine	90.3	--	--	--	23.8	53.0	13.5
White pine	86.9	--	--	6.3	18.4	42.9	19.3
Balsam fir	345.7	1.6	1.7	47.9	172.9	94.7	26.9
White spruce	34.4	--	--	--	3.1	17.2	14.1
Black spruce	59.5	--	--	--	--	4.4	55.1
Northern white-cedar	490.4	--	--	--	--	38.5	451.9
Tamarack	22.3	--	--	--	--	11.0	11.3
Oak-hickory	547.1	--	--	13.1	160.4	346.6	27.0
Elm-ash-soft maple	426.1	--	--	--	83.4	89.7	253.0
Maple-birch	481.0	--	--	21.5	111.3	267.4	80.8
Aspen	1,403.7	--	--	52.2	624.9	726.6	--
Paper birch	128.5	--	--	1.9	2.2	102.9	21.5
Exotic	9.3	--	--	--	2.2	7.1	--
All types	4,462.3	1.6	1.7	142.9	1,216.8	1,894.1	1,205.2
THINNING							
Red pine	121.7	--	--	18.2	59.3	44.2	--
White pine	2.5	--	--	--	2.5	--	--
White spruce	4.4	--	--	--	1.5	2.9	--
Oak-hickory	141.5	--	--	--	26.5	115.0	--
Maple-birch	1,407.5	--	--	35.4	260.5	869.6	242.0
All types	1,677.6	--	--	53.6	350.3	1,031.7	242.0
TIMBER STAND IMPROVEMENT							
Red pine	1.7	--	--	--	1.7	--	--
Oak-hickory	68.3	--	--	--	13.9	47.6	6.8
Maple-birch	1,171.0	--	--	34.5	239.8	657.1	239.6
All types	1,241.0	--	--	34.5	255.4	704.7	246.4
RELEASE							
Jack pine	207.8	--	--	--	2.6	27.1	178.1
White pine	44.2	--	--	4.3	14.8	17.4	7.7
Balsam fir	100.1	--	1.6	10.1	48.7	17.3	22.4
White spruce	30.0	--	--	--	14.7	15.3	--
Northern white-cedar	116.0	--	--	--	--	5.1	110.9
Maple-birch	16.4	--	--	--	6.5	8.3	1.6
All types	514.5	--	1.6	14.4	87.3	90.5	320.7

(Table 4 continued on next page)

(Table 4 continued)

Forest type	All classes	Site class 225+	165-224	120-164	85-119	50-84	20-49
RESTOCKING							
Jack pine	75.4	--	--	--	--	10.3	65.1
Red pine	36.2	--	--	--	5.4	27.8	3.0
White pine	16.9	--	--	1.7	--	9.8	5.4
Balsam fir	17.9	--	--	--	14.8	--	3.1
White spruce[1/]	7.8	--	--	--	4.6	3.2	--
Black spruce[1/]	16.7	--	--	--	--	--	16.7
Northern white-cedar[1/]	19.0	--	--	--	--	10.7	8.3
Tamarack[1/]	7.4	--	--	--	--	1.8	5.6
Oak-hickory	38.7	--	--	4.9	--	27.8	6.0
Elm-ash-soft maple	95.2	--	--	--	18.2	16.3	60.7
Maple-birch	117.7	--	--	--	7.8	68.6	41.3
Aspen[1/]	117.8	--	--	--	57.3	60.5	--
Exotic	3.5	--	--	--	--	3.5	--
All types	570.2	--	--	6.6	108.1	240.3	215.2
STAND CONVERSION							
Oak-hickory	534.3	--	--	--	--	--	534.3
Maple-birch	1,029.9	--	--	--	--	--	1029.9
Aspen	683.8	--	--	--	--	191.1	492.7
Paper birch	189.6	--	--	--	--	21.5	168.1
All types	2,437.6	--	--	--	--	212.6	2,225.0
NONSTOCKED							
Nonstocked	172.2	--	--	2.4	13.8	48.3	107.7
HYDRIC SITES							
Jack pine	4.1	--	--	--	--	1.6	2.5
Red pine	1.7	--	--	--	--	1.7	--
White pine	5.4	--	--	--	--	--	5.4
Balsam fir	39.6	--	--	--	12.0	16.2	11.4
White spruce	1.4	--	--	--	--	1.4	--
Black spruce	144.2	--	--	--	--	5.5	138.7
Northern white-cedar	150.2	--	--	--	--	7.5	142.7
Tamarack	47.6	--	--	--	--	7.3	40.3
Elm-ash-soft maple	127.4	--	--	--	14.7	31.9	80.8
Maple-birch	15.4	--	--	--	--	2.7	12.7
Aspen	43.6	--	--	--	30.6	2.3	10.7
Paper birch	5.9	--	--	--	--	--	5.9
All types	586.5	--	--	--	57.3	78.1	451.1

[1/] Artificial regeneration is not usually practiced in this type.

Table 5.--Area of commercial forest land by ownership class, site class, and treatment, Michigan, 1981-1990

(In thousand acres)

Forest type	All classes	Site class					
		225+	165-224	120-164	85-119	50-84	20-49
HARVEST							
National forest	482.2	--	--	7.4	76.7	265.1	133.0
Miscellaneous federal	12.7	--	--	1.5	8.3	--	2.9
State	965.7	1.6	1.7	28.8	230.7	353.2	349.7
County and municipal	39.7	--	--	--	16.7	13.1	9.9
Indian	9.8	--	--	--	1.7	6.6	1.5
Forest industry	447.8	--	--	14.5	74.5	158.8	200.0
Farmer	812.3	--	--	30.6	290.1	346.0	145.6
Miscellaneous private	1,692.1	--	--	60.1	518.1	751.3	362.6
All owners	4,462.3	1.6	1.7	142.9	1,216.8	1,894.1	1,205.2
THINNING							
National forest	320.8	--	--	3.0	59.2	193.8	64.8
Miscellaneous federal	1.6	--	--	--	--	1.6	--
State	236.7	--	--	7.0	33.6	178.2	17.9
County and municipal	27.0	--	--	2.6	6.6	12.9	4.9
Indian	4.9	--	--	--	--	4.9	--
Forest industry	206.6	--	--	1.5	23.8	129.2	52.1
Farmer	341.2	--	--	27.0	113.3	175.6	25.3
Miscellaneous private	538.8	--	--	12.5	113.8	335.5	77.0
All owners	1,677.6	--	--	53.6	350.3	1,031.7	242.0
TIMBER STAND IMPROVEMENT							
National forest	86.2	--	--	--	13.2	41.8	31.2
State	190.7	--	--	--	32.7	123.4	34.6
County and municipal	14.0	--	--	--	1.6	10.8	1.6
Forest industry	194.3	--	--	--	28.3	112.9	53.1
Farmer	318.1	--	--	21.4	87.8	163.6	45.3
Miscellaneous private	437.7	--	--	13.1	91.8	252.2	80.6
All owners	1,241.0	--	--	34.5	255.4	704.7	246.4
RELEASE							
National forest	130.6	--	--	--	8.4	6.3	115.9
State	149.8	--	--	4.8	16.6	27.5	100.9
County and municipal	4.8	--	--	--	2.5	--	2.3
Forest industry	66.2	--	--	1.6	27.2	15.0	22.4
Farmer	56.1	--	--	3.9	10.5	11.8	29.9
Miscellaneous private	107.0	--	1.6	4.1	22.1	29.9	49.3
All owners	514.5	--	1.6	14.4	87.3	90.5	320.7

(Table 5 continued on next page)

(Table 5 continued)

Forest type	All classes	Site class 225+	165-224	120-164	85-119	50-84	20-49
RESTOCKING							
National forest	51.1	--	--	--	14.1	13.5	23.5
Miscellaneous federal	5.4	--	--	--	--	5.4	--
State	127.7	--	--	--	19.6	50.7	57.4
County and municipal	4.6	--	--	--	--	4.6	--
Indian	1.6	--	--	--	--	1.6	--
Forest industry	23.4	--	--	--	4.2	10.3	8.9
Farmer	137.8	--	--	6.6	15.2	56.7	59.3
Miscellaneous private	218.6	--	--	--	55.0	97.5	66.1
All owners	570.2	--	--	6.6	108.1	240.3	215.2
STAND CONVERSION							
National forest	395.4	--	--	--	--	39.3	356.1
Miscellaneous federal	11.0	--	--	--	--	--	11.0
State	534.4	--	--	--	--	61.8	472.6
County and municipal	17.5	--	--	--	--	--	17.5
Indian	1.5	--	--	--	--	--	1.5
Forest industry	369.9	--	--	--	--	13.6	356.3
Farmer	273.0	--	--	--	--	23.6	249.4
Miscellaneous private	834.9	--	--	--	--	74.3	760.6
All owners	2,437.6	--	--	--	--	212.6	2,225.0
NONSTOCKED							
National forest	24.6	--	--	--	--	19.4	5.2
Miscellaneous federal	2.8	--	--	--	--	--	2.8
State	50.4	--	--	--	3.2	6.8	40.4
Forest industry	4.3	--	--	--	--	--	4.3
Farmer	26.6	--	--	--	5.4	--	21.2
Miscellaneous private	63.5	--	--	2.4	5.2	22.1	33.8
All owners	172.2	--	--	2.4	13.8	48.3	107.7
HYDRIC SITES							
National forest	88.8	--	--	--	34.9	--	53.9
State	145.1	--	--	--	--	21.0	124.1
County and municipal	2.9	--	--	--	--	--	2.9
Forest industry	92.8	--	--	--	1.6	12.4	78.8
Farmer	84.3	--	--	--	12.8	22.0	49.5
Miscellaneous private	172.6	--	--	--	8.0	22.7	141.9
All owners	586.5	--	--	--	57.3	78.1	451.1

Table 6.--Area of commercial forest land by treatment and stand-area class, Michigan, 1981-1990

(In thousand acres)

Treatment	All classes	Stand-area class (acres) 1-4	5-9	10-19	20-39	40-79	80-159	160-319	320-639	640+
Harvest	4,462.3	828.2	775.6	989.5	865.2	248.4	198.7	492.4	29.9	34.4
Thinning	1,677.6	217.6	234.4	303.9	458.4	121.6	73.4	214.2	17.2	36.9
Timber stand improvement	1,241.0	187.8	228.8	292.0	191.2	85.9	70.7	164.0	5.0	15.6
Release	514.5	183.7	103.8	79.0	59.6	5.9	31.6	45.5	--	5.4
Restocking	570.2	246.5	118.5	68.7	69.3	23.8	17.3	21.6	4.5	--
Stand conversion	2,437.6	583.5	438.0	479.3	481.7	111.5	77.6	229.7	4.6	31.7
Nonstocked	172.2	51.1	51.6	17.4	7.5	8.9	14.8	18.5	--	2.4
Hydric sites	586.5	211.6	113.8	96.3	49.9	17.0	19.3	76.3	--	2.3

Table 7.--Area of commercial forest land qualifying for harvest by forest type and stand-age class, Michigan, 1981-1990

(In thousand acres)

Forest type	All classes	Stand-age class (years)												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	337.1	--	--	--	--	133.2	107.0	38.3	34.8	14.6	4.4	2.3	2.5	--
Red pine	90.3	--	--	--	--	--	9.2	23.5	16.1	14.1	7.7	18.2	1.5	--
White pine	86.9	--	--	--	--	--	--	--	15.3	22.9	20.4	13.0	10.6	4.7
Balsam fir	345.7	--	--	--	--	51.4	91.5	57.1	42.2	22.5	12.9	23.6	9.7	4.8
White spruce	34.4	--	--	--	--	--	6.6	3.3	4.6	7.9	--	9.6	--	2.2
Black spruce	59.5	--	--	--	--	--	--	18.8	10.7	3.2	3.2	10.5	7.3	5.8
Northern white-cedar	490.4	--	--	--	--	--	--	--	63.5	117.3	74.5	117.0	62.4	55.7
Tamarack	22.3	--	--	--	--	--	8.6	5.8	3.3	1.5	2.9	--	--	--
Oak-hickory	547.1	--	--	--	--	--	--	65.4	146.2	117.9	71.9	118.5	23.8	3.4
Elm-ash-soft maple	426.1	--	--	--	--	--	--	54.8	89.1	65.2	45.0	91.8	45.9	14.3
Maple-birch	481.0	--	--	--	--	--	29.8	48.7	64.6	86.4	73.9	129.5	40.4	8.5
Aspen	1,403.7	--	--	--	172.7	433.6	358.5	178.4	127.1	69.8	51.2	32.4	--	--
Paper birch	128.5	--	--	--	--	18.9	74.0	24.7	5.5	--	3.9	1.5	--	--
Exotic	9.3	--	--	--	--	2.2	7.1	--	--	--	--	--	--	--
All types	4,462.3	--	--	--	172.7	668.3	671.7	518.8	623.2	568.3	371.9	567.9	204.1	99.4

Table 8.--Area of commercial forest land qualifying for thinning by forest type and stand-age class, Michigan, 1981-1990

(In thousand acres)

Forest type	All classes	Stand-age class (years)												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Red pine	121.7	--	--	66.0	43.4	12.3	--	--	--	--	--	--	--	--
White pine	2.5	--	--	--	--	--	2.5	--	--	--	--	--	--	--
Balsam fir	--	--	--	--	--	--	--	--	--	--	--	--	--	--
White spruce	4.4	--	--	--	--	4.4	--	--	--	--	--	--	--	--
Black spruce	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Northern white-cedar	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tamarack	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oak-hickory	141.5	--	--	4.1	43.7	61.1	32.6	--	--	--	--	--	--	--
Elm-ash-soft maple	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Maple-birch	1,407.5	--	--	20.8	97.9	362.9	313.4	156.1	83.6	110.8	89.3	120.3	43.3	9.1
Aspen	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paper birch	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Exotic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	1,677.6	--	--	90.9	185.0	440.7	348.5	156.1	83.6	110.8	89.3	120.3	43.3	9.1

Table 9.--Average annual growing-stock and sawtimber removals on commercial forest land qualifying for harvest by species group and tree class, Michigan, 1981-1990

Species group	Total all live	Growing-stock			Short-log cull	Rough and rotten cull	Sawtimber
		Total	Poletimber	Sawtimber			
	Thousand cubic feet						Thousand board feet[1/]
Softwoods							
Jack pine	33,653	33,010	15,314	17,696	167	476	88,749
Red pine	20,690	20,596	2,950	17,646	37	57	98,561
White pine	28,409	28,011	1,524	26,487	146	252	146,646
White spruce	26,089	25,618	5,340	20,278	71	400	102,876
Black spruce	11,409	11,345	8,122	3,223	4	60	15,637
Balsam fir	43,488	42,936	27,616	15,320	79	473	70,972
Hemlock	8,692	8,216	1,166	7,050	197	279	41,201
Tamarack	2,869	2,817	1,600	1,217	11	41	5,559
Eastern redcedar	22	22	--	22	--	--	103
Northern white-cedar	78,123	71,886	34,908	36,978	1,309	4,928	179,082
Other softwoods	1,087	1,032	241	791	--	55	3,659
Total	254,531	245,489	98,781	146,708	2,021	7,021	753,045
Hardwoods							
White oak	29,365	28,292	3,519	24,773	376	697	134,704
Select red oak	45,976	44,433	5,557	38,876	621	922	210,758
Other red oak	11,970	11,171	1,034	10,137	157	642	54,526
Hickory	5,574	5,466	1,058	4,408	87	21	23,207
Basswood	6,998	6,496	1,973	4,523	69	433	23,673
Beech	1,686	1,482	665	817	37	167	4,559
Yellow birch	6,376	5,378	1,458	3,920	309	689	21,320
Hard maple	20,757	18,254	7,992	10,262	685	1,818	53,563
Soft maple	79,650	74,193	26,696	47,497	1,164	4,293	234,627
Elm	6,293	6,078	2,247	3,831	46	169	22,111
Black ash	11,409	11,000	5,621	5,379	52	357	29,868
White and green ash	10,606	10,422	2,756	7,666	81	103	41,691
Sycamore	318	318	--	318	--	--	1,557
Cottonwood	2,983	2,979	15	2,964	--	4	14,952
Willow	1,236	1,086	47	1,039	--	150	5,430
Hackberry	94	94	27	67	--	--	380
Balsam poplar	13,917	13,692	1,746	11,946	38	187	64,876
Bigtooth aspen	60,694	58,380	15,545	42,835	359	1,955	228,269
Quaking aspen	100,591	94,073	26,216	67,857	882	5,636	363,433
Paper birch	43,058	40,705	21,904	18,801	219	2,134	101,933
River birch	32	32	19	13	--	--	76
Black cherry	8,088	7,357	2,139	5,218	204	527	28,100
Black walnut	1,113	1,094	63	1,031	--	19	4,913
Butternut	118	96	--	96	--	22	488
Yellow poplar	248	248	--	248	--	--	1,269
Other hardwoods	1,430	1,260	799	461	9	161	2,523
Total	470,580	444,079	129,096	314,983	5,395	21,106	1,672,806
All species	725,111	689,568	227,877	461,691	7,416	28,127	2,425,851

[1/] International 1/4-inch rule.

Table 10.--Average annual growing-stock and sawtimber removals on commercial forest land qualifying for thinning by species group and tree class, Michigan, 1981-1990

Species group	Total all live	Growing-stock			Short-log cull	Rough and rotten cull	Sawtimber
		Total	Poletimber	Sawtimber			
	Thousand cubic feet						Thousand board feet[1/]
Softwoods							
Jack pine	1,427	1,308	1,062	246	29	90	1,248
Red pine	11,363	11,208	10,004	1,204	--	155	6,856
White pine	906	863	234	629	14	29	3,199
White spruce	539	539	336	203	--	--	1,017
Black spruce	208	208	160	48	--	--	214
Balsam fir	3,304	3,268	2,709	559	--	36	2,549
Hemlock	1,737	1,636	764	872	24	77	4,901
Tamarack	9	9	9	--	--	--	--
Eastern redcedar	--	--	--	--	--	--	--
Northern white-cedar	1,907	1,700	1,123	577	8	199	2,697
Other softwoods	235	235	235	--	--	--	--
Total	21,635	20,974	16,636	4,338	75	586	22,681
Hardwoods							
White oak	1,751	1,635	839	796	33	83	4,222
Select red oak	2,522	2,369	1,836	533	57	96	2,556
Other red oak	827	721	451	270	106	--	1,458
Hickory	558	526	313	213	--	32	1,018
Basswood	4,929	4,766	3,204	1,562	--	163	6,720
Beech	841	764	489	275	34	43	1,429
Yellow birch	645	609	476	133	9	27	683
Hard maple	37,734	35,833	18,984	16,849	173	1,728	85,571
Soft maple	24,883	23,743	14,999	8,744	114	1,026	35,301
Elm	2,737	2,572	1,776	796	22	143	5,070
Black ash	931	905	810	95	--	26	503
White-green ash	3,026	2,911	1,718	1,193	69	46	6,217
Sycamore	68	68	20	48	--	--	259
Cottonwood	144	144	27	117	--	--	624
Willow	--	--	--	--	--	--	--
Hackberry	--	--	--	--	--	--	--
Balsam poplar	60	52	22	30	--	8	172
Bigtooth aspen	3,721	3,601	2,070	1,531	--	120	8,063
Quaking aspen	2,922	2,719	1,468	1,251	7	196	6,487
Paper birch	2,573	2,468	1,519	949	--	105	5,135
River birch	--	--	--	--	--	--	--
Black cherry	3,475	3,247	1,903	1,344	--	228	8,258
Black walnut	333	298	87	211	35	--	1,111
Butternut	--	--	--	--	--	--	--
Yellow poplar	--	--	--	--	--	--	--
Other hardwoods	380	380	118	262	--	--	1,463
Total	95,060	90,331	53,129	37,202	659	4,070	182,320
All species	116,695	111,305	69,765	41,540	734	4,656	205,001

[1/] International 1/4-inch rule.

Table 11.--Average annual growing-stock removals on commercial forest land qualifying for harvest by species group and forest type, Michigan, 1981-1990

(In thousand cubic feet)

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
Softwoods															
Jack pine	33,010	30,294	626	239	37	11	151	--	65	522	--	--	877	102	86
Red pine	20,596	3,491	10,648	1,442	422	87	100	75	--	664	--	22	3,283	250	112
White pine	28,011	967	2,658	9,757	2,629	417	455	2,655	--	1,362	1,358	749	4,402	391	211
White spruce	25,618	44	223	514	11,477	2,994	248	2,698	--	50	1,063	316	5,680	311	--
Black spruce	11,345	497	144	442	2,308	135	3,325	3,293	164	24	324	26	626	37	--
Balsam fir	42,936	149	248	319	17,445	795	667	5,773	107	20	2,285	552	13,472	1,104	--
Hemlock	8,216	--	129	160	700	9	92	1,036	--	83	1,522	3,450	789	246	--
Tamarack	2,817	--	--	43	176	--	209	722	1,225	--	136	19	208	79	--
Eastern redcedar	22	--	--	--	--	--	--	--	--	22	--	--	--	--	--
Northern white-cedar	71,886	--	54	139	4,480	1,001	1,550	51,774	271	--	5,080	599	5,807	1,119	12
Other softwoods	1,032	--	93	--	10	--	--	--	--	153	--	--	--	--	776
Total	245,489	35,442	14,823	13,055	39,684	5,449	6,797	68,026	1,832	2,900	11,768	5,733	35,144	3,639	1,197
Hardwoods															
White oak	28,292	200	112	362	--	--	--	--	--	24,235	1,487	428	1,413	55	--
Select red oak	44,433	2,212	689	404	59	--	--	--	--	29,544	798	1,239	8,986	502	--
Other red oak	11,171	765	98	--	--	--	--	--	--	9,704	130	--	437	0	37
Hickory	5,466	27	--	--	--	--	--	--	--	5,031	245	145	--	18	--
Basswood	6,496	15	--	--	14	--	--	52	--	771	1,866	1,649	1,851	278	--
Beech	1,482	--	--	33	--	--	--	--	--	310	187	437	508	7	--
Yellow birch	5,378	--	--	47	898	18	114	829	--	42	1,945	717	568	200	--
Hard maple	18,254	--	18	351	521	76	--	444	--	708	1,323	8,917	5,070	826	--
Soft maple	74,193	412	427	666	3,814	249	214	3,415	--	5,852	27,622	8,229	21,147	2,146	--
Elm	6,078	--	--	11	352	12	--	54	--	478	2,159	1,627	1,369	--	16
Black ash	11,000	--	--	--	286	--	116	1,375	11	274	7,594	137	1,104	103	--
White and green ash	10,422	--	--	--	23	--	--	88	--	1,504	4,711	2,462	1,501	133	--
Sycamore	318	--	--	--	--	--	--	--	--	46	184	88	--	--	--
Cottonwood	2,979	--	--	--	--	--	--	--	--	400	1,351	172	1,056	--	--
Willow	1,086	--	--	--	--	--	--	--	--	--	875	147	64	--	--
Hackberry	94	--	--	--	--	--	--	--	--	--	94	--	--	--	--
Balsam poplar	13,692	--	9	--	885	137	--	912	43	--	771	87	10,478	320	--
Bigtooth aspen	58,380	141	518	127	172	--	--	195	--	4,480	334	427	51,330	605	51
Quaking aspen	94,073	1,116	519	1,034	4,048	533	328	1,411	87	723	1,808	632	80,169	1,592	73
Paper birch	40,705	93	419	628	3,423	132	197	5,056	74	855	1,194	439	15,964	12,181	--
River birch	32	--	--	--	--	--	--	32	--	--	--	--	--	--	--
Black cherry	7,357	43	89	20	393	--	--	57	--	3,189	764	1,009	1,771	--	22
Black walnut	1,094	--	--	--	--	--	--	--	--	1,033	61	--	--	--	--
Butternut	96	--	--	--	--	--	--	--	--	15	81	--	--	--	--
Yellow poplar	248	--	--	--	--	--	--	--	--	102	101	45	--	--	--
Other hardwoods	1,260	27	--	--	--	--	--	--	--	943	189	--	101	--	--
Total	444,079	5,051	2,898	3,683	14,888	1,257	969	13,920	215	90,239	57,874	29,033	204,887	18,966	199
All species	689,568	40,493	17,721	16,738	54,572	6,706	7,766	81,946	2,047	93,139	69,642	34,766	240,031	22,605	1,396

Table 12.--Average annual growing-stock removals on commercial forest land qualifying for thinning by species group and forest type, Michigan, 1981-1990

(In thousand cubic feet)

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
Softwoods															
Jack pine	1,308	--	1,069	18	--	--	--	--	--	221	--	--	--	--	--
Red pine	11,208	--	10,192	50	--	28	--	--	--	477	--	461	--	--	--
White pine	863	--	149	79	--	107	--	--	--	59	--	469	--	--	--
White spruce	539	--	--	--	--	--	--	--	--	--	--	539	--	--	--
Black spruce	208	--	--	--	--	--	--	--	--	16	--	192	--	--	--
Balsam fir	3,268	--	58	--	--	17	--	--	--	--	--	3,193	--	--	--
Hemlock	1,636	--	--	--	--	8	--	--	--	--	--	1,628	--	--	--
Tamarack	9	--	--	--	--	--	--	--	--	--	--	9	--	--	--
Eastern redcedar	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Northern white-cedar	1,700	--	--	--	--	9	--	--	--	--	--	1,691	--	--	--
Other softwoods	235	--	40	--	--	--	--	--	--	--	--	195	--	--	--
Total	20,974	--	11,508	147	--	169	--	--	--	773	--	8,377	--	--	--
Hardwoods															
White oak	1,635	--	490	20	--	--	--	--	--	604	--	521	--	--	--
Select red oak	2,369	--	98	--	--	--	--	--	--	1,523	--	748	--	--	--
Other red oak	721	--	316	--	--	--	--	--	--	405	--	--	--	--	--
Hickory	526	--	--	--	--	--	--	--	--	243	--	283	--	--	--
Basswood	4,766	--	45	--	--	--	--	--	--	--	--	4,721	--	--	--
Beech	764	--	53	--	--	11	--	--	--	--	--	700	--	--	--
Yellow birch	609	--	--	--	--	--	--	--	--	--	--	609	--	--	--
Hard maple	35,833	--	18	--	--	--	--	--	--	--	--	35,815	--	--	--
Soft maple	23,743	--	322	15	--	12	--	--	--	1,587	--	21,807	--	--	--
Elm	2,572	--	--	--	--	--	--	--	--	81	--	2,491	--	--	--
Black ash	905	--	--	--	--	--	--	--	--	28	--	877	--	--	--
White and green ash	2,911	--	7	--	--	--	--	--	--	92	--	2,812	--	--	--
Sycamore	68	--	--	--	--	--	--	--	--	--	--	68	--	--	--
Cottonwood	144	--	--	--	--	--	--	--	--	82	--	62	--	--	--
Willow	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hackberry	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Balsam poplar	52	--	--	--	--	11	--	--	--	--	--	41	--	--	--
Bigtooth aspen	3,601	--	89	92	--	--	--	--	--	1,834	--	1,586	--	--	--
Quaking aspen	2,719	--	--	--	--	71	--	--	--	339	--	2,309	--	--	--
Paper birch	2,468	--	--	--	--	82	--	--	--	239	--	2,147	--	--	--
River birch	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Black cherry	3,247	--	117	14	--	--	--	--	--	252	--	2,864	--	--	--
Black walnut	298	--	--	--	--	--	--	--	--	298	--	--	--	--	--
Butternut	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Yellow poplar	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Other hardwoods	380	--	--	--	--	--	--	--	--	23	--	357	--	--	--
Total	90,331	--	1,555	141	--	187	--	--	--	7,630	--	80,818	--	--	--
All species	111,305	--	13,063	288	--	356	--	--	--	8,403	--	89,195	--	--	--

Table 13.--Average annual sawtimber removals on commercial forest land qualifying for harvest by species group and forest type, Michigan, 1981-1990

(In thousand board feet)[1/]

Species group	All types	Forest type													
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack	Oak-hickory	Elm-ash-maple	Maple-birch	Aspen	Paper birch	Exotic
Softwoods															
Jack pine	88,749	80,223	1,907	899	99	58	374	--	269	1,707	--	--	2,305	472	436
Red pine	98,561	15,783	53,643	7,925	2,183	490	551	331	--	2,504	--	136	13,843	916	256
White pine	146,646	4,218	13,003	51,894	14,084	2,217	2,382	15,416	--	7,000	7,592	3,820	22,376	1,835	809
White spruce	102,876	230	624	1,942	47,310	12,197	1,225	10,950	--	187	4,666	1,306	21,025	1,214	--
Black spruce	15,637	325	--	661	4,299	324	2,771	5,068	344	74	876	93	802	--	--
Balsam fir	70,972	646	401	472	31,888	1,799	593	7,186	141	--	3,402	629	22,038	1,777	--
Hemlock	41,201	--	417	970	3,841	59	544	6,143	--	454	7,612	17,498	2,674	989	--
Tamarack	5,559	--	--	163	477	--	393	1,417	1,908	--	567	88	546	--	--
Eastern redcedar	103	--	--	--	--	--	--	--	--	103	--	--	--	--	--
Northern white-cedar	179,082	--	71	282	13,597	2,687	5,319	125,618	511	--	14,355	2,112	12,798	1,732	--
Other softwoods	3,659	--	186	--	--	--	--	--	--	698	--	--	--	--	2,775
Total	753,045	101,425	70,252	65,208	117,778	19,831	14,152	172,129	3,173	12,727	39,070	25,682	98,407	8,935	4,276
Hardwoods															
White oak	134,704	817	637	1,977	--	--	--	--	--	115,377	7,980	2,143	5,525	248	--
Select red oak	210,758	8,068	3,414	1,359	131	--	--	--	--	147,078	3,930	6,512	38,081	2,185	--
Other red oak	54,526	2,919	567	--	--	--	--	--	--	48,363	742	--	1,762	--	173
Hickory	23,207	141	--	--	--	--	--	--	--	21,824	803	343	--	96	--
Basswood	23,673	--	--	--	--	--	--	287	--	2,653	7,747	5,508	6,113	1,365	--
Beech	4,559	--	--	128	--	--	--	--	--	1,051	917	1,682	739	42	--
Yellow birch	21,320	--	--	200	4,215	53	554	3,845	--	69	8,535	2,207	1,320	322	--
Hard maple	53,563	--	110	1,131	1,794	224	--	1,396	--	2,967	5,023	27,948	10,535	2,435	--
Soft maple	234,627	958	479	1,507	9,216	181	434	8,704	--	16,593	120,654	28,638	43,387	3,876	--
Elm	22,111	--	--	--	1,100	70	--	230	--	315	7,426	8,090	4,880	--	--
Black ash	29,868	--	--	--	577	--	292	2,122	--	474	24,504	285	1,460	154	--
White and green ash	41,691	--	--	--	--	--	--	202	--	7,127	18,008	11,623	4,293	438	--
Sycamore	1,557	--	--	--	--	--	--	--	--	232	904	421	--	--	--
Cottonwood	14,952	--	--	--	--	--	--	--	--	1,998	6,776	920	5,258	--	--
Willow	5,430	--	--	--	--	--	--	--	--	--	4,373	728	329	--	--
Hackberry	380	--	--	--	--	--	--	--	--	--	380	--	--	--	--
Balsam poplar	64,876	--	55	--	4,487	976	--	5,294	139	--	4,123	393	47,849	1,510	--
Bigtooth aspen	228,269	439	1,369	689	890	--	--	1,009	--	17,413	1,646	1,969	200,257	2,588	--
Quaking aspen	363,433	3,259	1,086	3,017	16,024	1,800	1,376	6,499	285	1,903	8,983	2,703	310,020	6,280	198
Paper birch	101,933	72	962	2,402	9,669	471	655	14,222	171	2,790	5,063	1,378	37,275	26,803	--
River birch	76	--	--	--	--	--	--	76	--	--	--	--	--	--	--
Black cherry	28,100	108	317	106	1,251	--	--	262	--	13,863	2,102	4,156	5,804	--	131
Black walnut	4,913	--	--	--	--	--	--	--	--	4,622	291	--	--	--	--
Butternut	488	--	--	--	--	--	--	--	--	65	423	--	--	--	--
Yellow poplar	1,269	--	--	--	--	--	--	--	--	537	492	240	--	--	--
Other hardwoods	2,523	--	--	--	--	--	--	--	--	2,021	359	--	143	--	--
Total	1,672,806	16,781	8,996	12,515	49,354	3,775	3,311	44,148	645	409,335	242,184	107,887	725,030	48,342	502
All species	2,425,851	118,206	79,248	77,724	167,132	23,606	17,463	216,277	3,818	422,062	281,254	133,569	823,437	57,277	4,778

[1/] International 1/4-inch rule.

Table 14.--Average annual growing-stock removals on commercial forest land qualifying for harvest by forest type and stand-age class, Michigan, 1981-1990

(In thousand cubic feet)

Forest type	All classes	Stand-age class												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	40,493	--	--	--	--	16,465	12,264	5,002	4,500	1,465	497	189	111	--
Red pine	17,721	--	--	--	--	--	1,304	4,532	2,835	2,912	2,036	3,861	241	--
White pine	16,738	--	--	--	--	--	--	--	2,327	4,511	4,190	2,323	2,207	1,180
Balsam fir	54,572	--	--	--	--	14,230	12,637	8,968	6,555	3,696	2,410	3,912	1,504	660
White spruce	6,706	--	--	--	--	--	1,046	1,082	796	1,557	--	1,839	--	386
Black spruce	7,766	--	--	--	--	--	--	2,029	1,582	375	379	1,591	1,119	691
Northern white-cedar	81,946	--	--	--	--	--	--	--	9,948	18,354	13,624	19,473	10,857	9,690
Tamarack	2,047	--	--	--	--	--	627	523	342	167	388	--	--	--
Oak-hickory	93,139	--	--	--	--	--	--	10,429	25,611	18,245	11,445	22,812	4,257	340
Elm-ash-soft maple	69,642	--	--	--	--	--	--	8,539	13,369	14,925	8,197	14,974	7,153	2,485
Maple-birch	34,766	--	--	--	--	--	2,095	3,508	4,419	6,096	5,658	9,278	3,070	642
Aspen	240,031	--	--	--	26,391	68,535	58,979	34,956	25,096	11,661	7,515	6,898	--	--
Paper birch	22,605	--	--	--	--	3,457	13,101	3,992	1,123	--	647	285	--	--
Exotic	1,396	--	--	--	--	261	1,135	--	--	--	--	--	--	--
All types	689,568	--	--	--	26,391	102,948	103,188	83,560	98,503	83,964	56,986	87,435	30,519	16,074

Table 15.--Average annual growing-stock removals on commercial forest land qualifying for thinning by forest type and stand-age class, Michigan, 1981-1990

(In thousand cubic feet)

Forest type	All classes	Stand-age class												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Red pine	13,063	--	--	6,156	5,939	968	--	--	--	--	--	--	--	--
White pine	288	--	--	--	--	--	288	--	--	--	--	--	--	--
Balsam fir	--	--	--	--	--	--	--	--	--	--	--	--	--	--
White spruce	356	--	--	--	--	356	--	--	--	--	--	--	--	--
Black spruce	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Northern white-cedar	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tamarack	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oak-hickory	8,403	--	--	125	2,296	3,714	2,268	--	--	--	--	--	--	--
Elm-ash-soft maple	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Maple-birch	89,195	--	--	1,152	6,129	22,434	19,711	10,575	5,112	6,948	5,412	8,347	2,532	843
Aspen	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paper birch	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Exotic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	111,305	--	--	7,433	14,364	27,472	22,267	10,575	5,112	6,948	5,412	8,347	2,532	843

Table 16.--Average annual growing-stock removals per acre on commercial forest land qualifying for harvest by forest type and stand-age class, Michigan, 1981-1990

(In cubic feet per acre)

Forest type	All classes	Stand-age class												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	1,201	--	--	--	--	1,236	1,146	1,305	1,295	1,002	1,132	816	447	--
Red pine	1,962	--	--	--	--	--	1,422	1,925	1,770	2,065	2,639	2,118	1,575	--
White pine	1,926	--	--	--	--	--	--	--	1,521	1,966	2,051	1,791	2,091	2,517
Balsam fir	1,578	--	--	--	--	1,747	1,381	1,572	1,554	1,643	1,864	1,661	1,547	1,361
White spruce	1,947	--	--	--	--	--	1,565	3,293	1,654	1,971	--	1,917	--	1,776
Black spruce	1,306	--	--	--	--	--	--	1,081	1,473	1,170	1,199	1,515	1,538	1,192
Northern white-cedar	1,671	--	--	--	--	--	--	--	1,566	1,564	1,831	1,664	1,741	1,738
Tamarack	917	--	--	--	--	--	708	899	1,048	1,109	1,346	--	--	--
Oak-hickory	1,702	--	--	--	--	--	--	1,595	1,751	1,548	1,591	1,925	1,787	1,008
Elm-ash-soft maple	1,634	--	--	--	--	--	--	1,559	1,500	1,752	1,820	1,632	1,557	1,743
Maple-birch	723	--	--	--	--	--	723	721	684	706	765	716	759	758
Aspen	1,710	--	--	--	1,528	1,581	1,743	1,959	1,975	1,671	1,469	2,130	--	--
Paper birch	1,759	--	--	--	--	1,826	1,772	1,615	2,034	--	1,669	1,885	--	--
Exotic	1,503	--	--	--	--	1,171	1,608	--	--	--	--	--	--	--
All types	1,545	--	--	--	1,528	1,538	1,536	1,611	1,581	1,491	1,532	1,540	1,495	1,618

Table 17.--Average annual growing-stock removals per acre on commercial forest land qualifying for thinning by forest type and stand-age class, Michigan, 1981-1990

(In cubic feet per acre)

Forest type	All classes	Stand-age class												
		1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-120	121-140	141+
Jack pine	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Red pine	1,074	--	--	933	1,370	785	--	--	--	--	--	--	--	--
White pine	1,153	--	--	--	--	--	1,153	--	--	--	--	--	--	--
Balsam fir	--	--	--	--	--	--	--	--	--	--	--	--	--	--
White spruce	803	--	--	--	--	803	--	--	--	--	--	--	--	--
Black spruce	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Northern white-cedar	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tamarack	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Oak-hickory	594	--	--	302	526	608	695	--	--	--	--	--	--	--
Elm-ash-soft maple	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Maple-birch	634	--	--	555	626	618	629	677	611	627	606	694	584	926
Aspen	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Paper birch	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Exotic	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All types	663	--	--	818	776	623	639	677	611	627	606	694	584	926

Smith, W. Brad; Spencer, John S., Jr.
Forest management opportunities for Michigan, 1981-1990. Res. Pap. NC-264. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 31 p.

Uses a computer model to identify commercial forest that would benefit from forest management and the volume of removals that would result. Targets 63 percent of the State's commercial area for treatment—primarily harvest, stand conversion, and thinning.

KEY WORDS: Forest treatments, timber harvest, growing-stock volume, commercial forest land.

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Ownership Change and Timber Supply on Nonindustrial Private Forest Land

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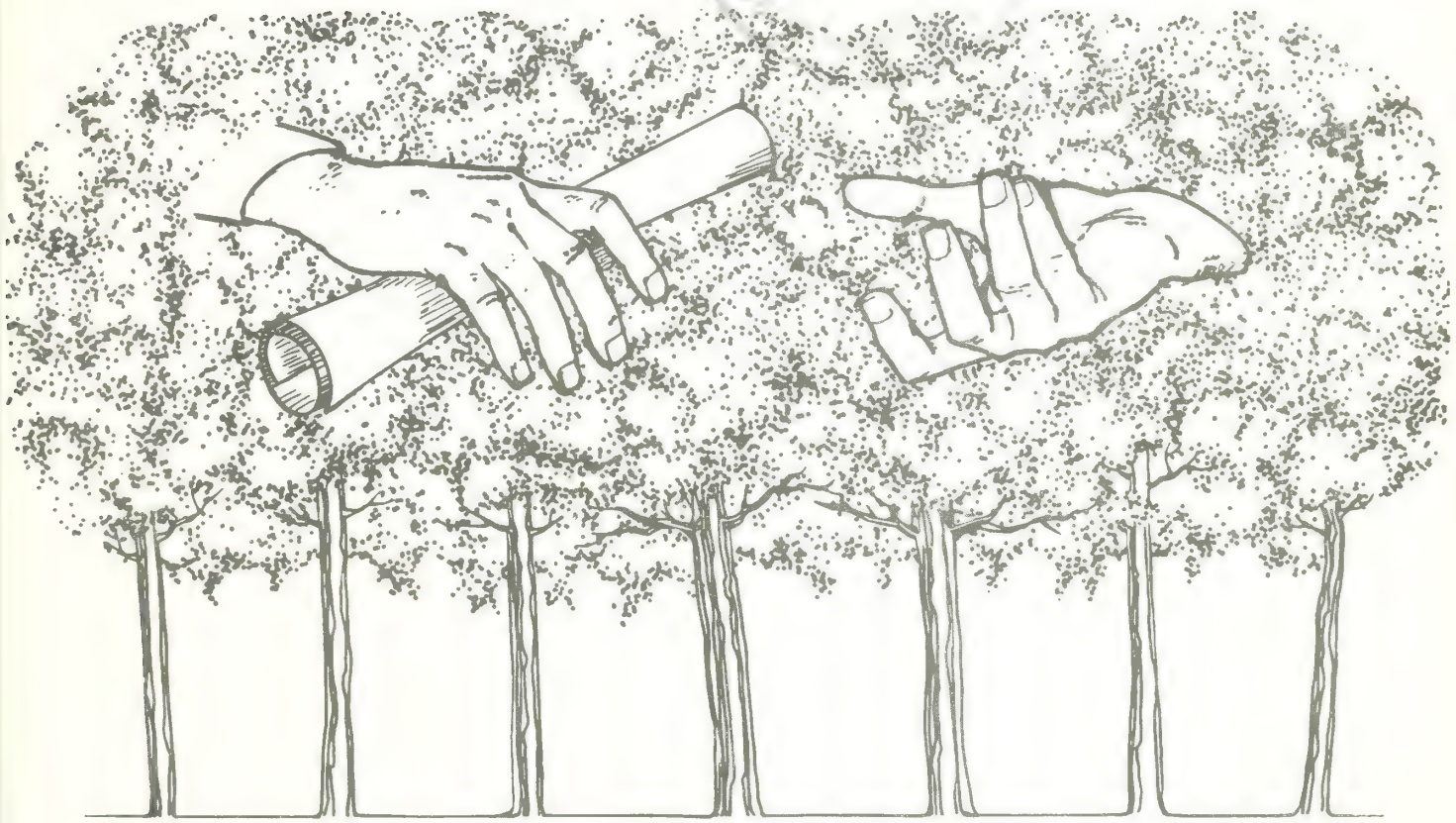

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CONTENTS

	Page
Background	1
Our Study	2
Current Owners	2
Distribution by Tenure and Residency	3
Some Properties Larger, Some Smaller	4
Division and Augmentation	4
Timber Harvest Attitudes	5
1967 Attitudes	5
1979 Attitudes	5
Changing Attitudes	5
Harvest Actions	5
Improvement Cut Attitudes	6
Other Owner Attitudes	6
Reason for Owning Forest Land	6
Owners with Changed Attitudes	6
Reasons for Harvesting	7
Reasons for Not Harvesting	7
Owner Characteristics	7
Age	7
Occupation	7
Summary	7
Literature Cited	8

OWNERSHIP CHANGE AND TIMBER SUPPLY ON NONINDUSTRIAL PRIVATE LAND

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Duluth, Minnesota

BACKGROUND

In the mid-1960's, Robert Stone described a seeming contradiction about private forest landowners as timber suppliers (Stone 1970). In reviewing 25 studies of nonindustrial private forest landowners (NIPFL's), he found that most researchers characterized these owners as having little interest in growing or supplying timber as a commercial enterprise. Consistently, one-quarter to one-third or more of NIPFL respondents indicated they would not harvest their timber. However, Stone also found in forest survey statistics that farmers and miscellaneous private owners provided a share of timber harvest and an amount cut per acre, annually, not much different from that harvested on public and industrial forests. Although small private forest holdings had slightly below average stocking and growth, consistent with a lack of conscious management effort, they actually harvested a proportionately larger amount of their volume and growth than did the other owner classes.

Concern about timber supply from NIPFL land is well founded bacause these owners control 58 percent of all commercial timberland in the United States and slightly more than 70 percent in the East (USDA 1978). Studies consistently find that a large proportion of private forest landowners say they will not harvest their timber. Also there is a perception that this land is being divided into smaller, less desirable, timber production units. Further, there is concern that nonresident owners are gaining control of a larger proportion of the commerical forest acreage pimarily for recreation or other nontimber uses.

We set out to determine what happened, over time, to an initial set of forest properties, to note what changes have occurred, and to examine how change may have affected timber supply and owner and property characteristics. We had a unique opportunity to take a third look at previously studied properties in Michigan's Upper Peninsula.

In 1960, Dean Quinney interviewed a sample of 197 private forest landowners in Michigan's Upper Peninsula to determine owner and property characteristics, to identify owner objectives and attitudes toward forest management and timber harvesting, and to evaluate how these forest properties might contribute to future timber supply and economic development of the area (Quinney 1962).

In 1967, Stone identified and interviewed the current owners of the land included in the 1960 study to compare landowner intentions expressed in 1960 with owner actions during the intervening 7 years. He found the proportion of owners holding certain attitudes, objectives, and intentions was reasonably consistent over time in the Upper Peninsula and consistent with findings of studies in other areas. However, some owners of the study land had taken actions different from previously stated intentions. Either the same owners had changed their minds or different owners held different attitudes and objectives. Thus, while the proportion of owners planning to harvest timber, or having positive or negative attitudes about harvesting or other management activities, may be fixed at any particular time, these are momentary snapshots of the situation. Stone postulated that relative to timber harvesting, these private owners operate in an economically rational manner as indicated by forest survey statistics. They attempt to keep their investment in timber capital low to satisfy their high time preference for money, and many will harvest timber as it becomes marketable. Timber growth does proceed regardless of forest management intensity. Eventually, an owner becomes aware of the timber value and conducts a timber harvest, perhaps contrary to a previously held intention. Consequently, over time, particularly as long as a forest management rotation period, these dynamic forces would probably make most private timber available for harvest.

In his analysis of the period from 1960 to 1967, Stone reported that the number of owners holding some of the original forest acres had increased by 19

percent—from 197 to 235 owners. Three original properties, containing 90 acres of forest, had been platted and subdivided and were dropped from his study. Also, it was not possible to interview 10 owners in 1967[1]. This left 222 respondents with some of the original forest land. Forty-six percent were different owners in 1967. There were 19 more nonresident respondents and 6 more resident respondents. Thirty-three original properties had partially or completely changed in residence status with the net effect of shifting 639 original resident-held forest acres (3 percent) to nonresident owners. The average size of these new, nonresident forest holdings was larger (88 acres) than the original resident properties (72 acres) or the residual resident holdings (44 acres) (fig. 1). When nonresident holdings shifted to resident status, the average size decreased by about 11 forest acres (fig. 2).

[1]*The owners of these properties were identified and mailed a questionnaire in 1979.*

OUR STUDY

Current Owners

In 1979, we updated the owner list of the original 1960 study land and mailed each owner a questionnaire[2]. To be included in our 1979 study, a person had to own some portion of the 1960 land base.

We identified 293 separately owned properties in 1979 that included land from the original 1960 descriptions[3]. This compares with 197 properties in 1960 and 232 in 1967. In 1979, the State of Michigan owned two of the 1967 properties (78 forested acres) and a large mining company had purchased two

[2]*Copies of questionnaire are available from: Publications, USDA Forest Service, 1992 Folwell Avenue, St. Paul, MN 55108.*

[3]*One additional property involving 20 forested acres had been platted and subdivided since 1967 and the owners were not determined in 1979.*

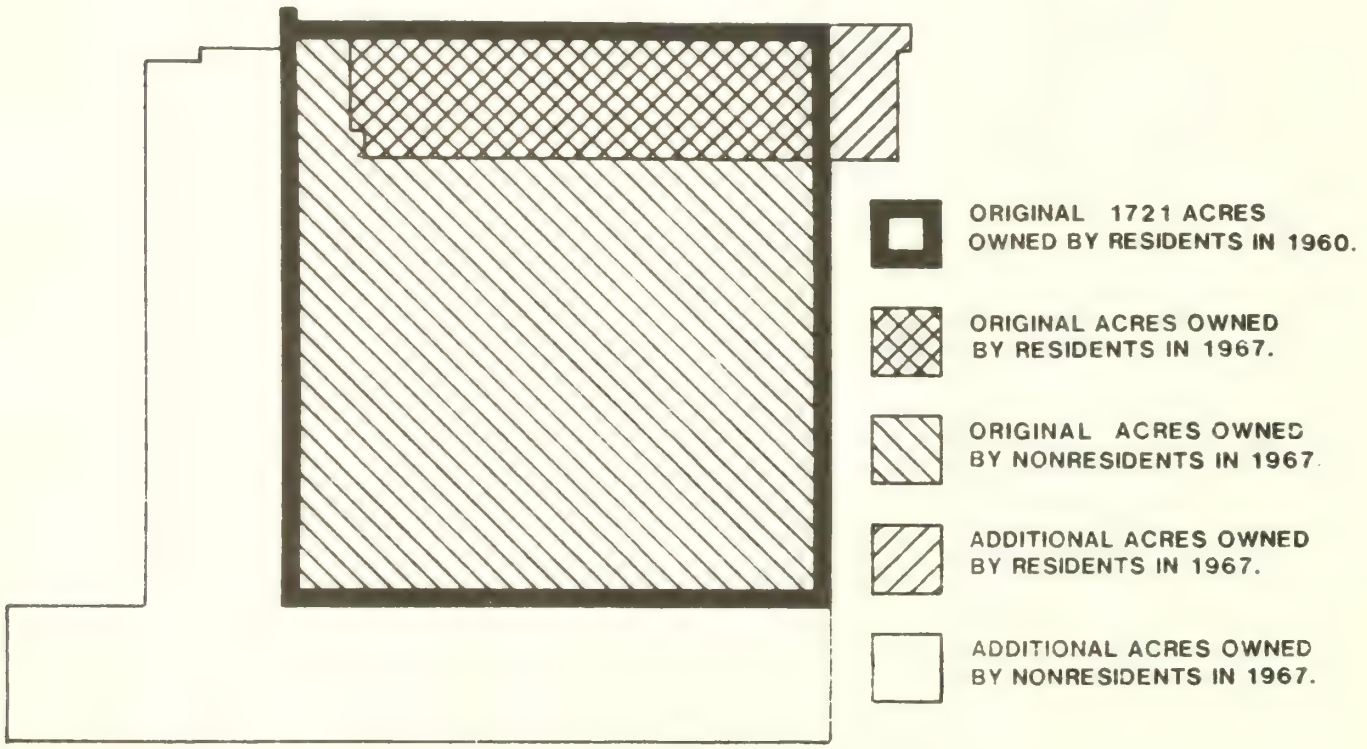
ORIGINAL 1721 ACRES OWNED BY RESIDENTS IN 1960.
ORIGINAL ACRES OWNED BY RESIDENTS IN 1967.
ORIGINAL ACRES OWNED BY NONRESIDENTS IN 1967.
ADDITIONAL ACRES OWNED BY RESIDENTS IN 1967.
ADDITIONAL ACRES OWNED BY NONRESIDENTS IN 1967.
1960
1967
24 OWNERS
36 OWNERS (27 NONRESIDENT, 9 RESIDENT).
1721 ACRES
2779 ACRES (2379 NONRESIDENT ACRES, 400 RESIDENT ACRES).

Figure 1.—*Changes from resident ownership 1960 to 1967.*

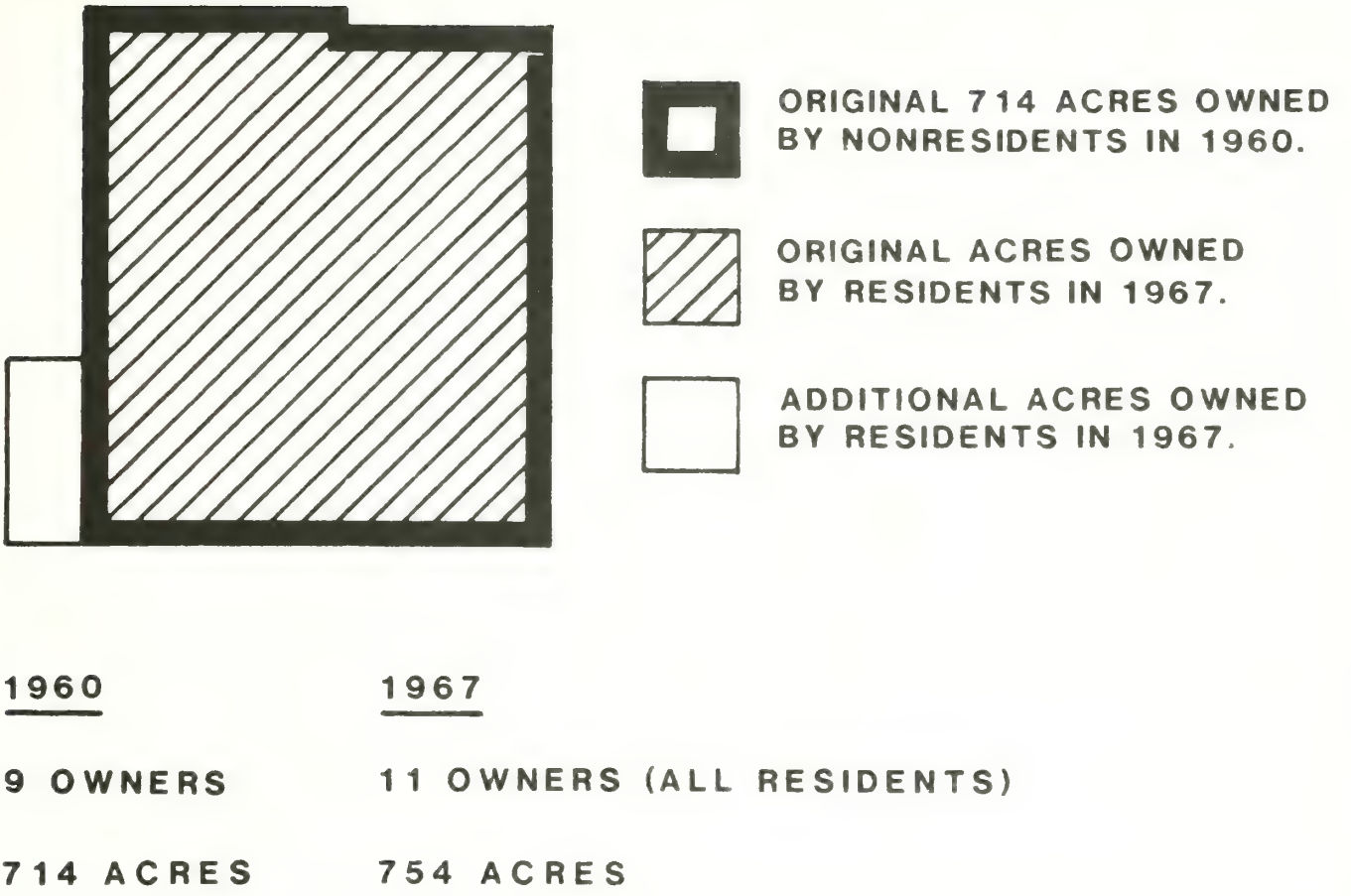

Figure 2.—*Changes from nonresident ownership 1960 to 1967.*

others (182 forested acres). These two owners, holding 0.9 percent of the 1967 acres (4 ownerships, 260 acres), were dropped from our analysis, leaving 291 separate properties. Of these, 20 respondents reported owning no forested acreage in 1979. Some of these owners may have purchased a nonforest portion of a 1960 tract or a small houselot that they did not consider to be forest land. Thus, we found that 271 owners held 37,211 forested acres in 1979, for an increase of 37 percent and 83 percent, respectively, since 1960 (table 1). Each owned some of the 1960 forest property.

Distribution by Tenure and Residency

In 1979, 38 percent of the 1960 owners still owned some of the original forest land. They represent 34 percent of the 1967 owners and 28 percent of the 1979 owners. Twenty-nine percent of the 1960 properties were still intact under the same owner, representing 26 percent of the 1967 owners and 21 percent of the 1979 owners. From 1967 to 1979, resident properties increased by 16 percent, nonresident increased by 40 percent. Thus, the trend towards increasing nonresident ownership continued from 1967. There were 89 different resident owners and 60 different nonresident owners.

Where new owners were involved in 1979:

- Seventy-five different resident owners had forest land formerly owned by a resident.
- Twenty-seven different nonresident owners had property formerly owned by a nonresident.
- Fourteen properties formerly in nonresident status shifted, at least in part, to resident status.
- Thirty-three properties formerly in resident status shifted to nonresident.

Forty-six percent of the 1967 owners were different from those in 1960; 55 percent of the 1979 owners were different from those in 1967. Seventy-two percent of 1979 owners were different from those in 1960. This tremendous turnover in owners highlights the dynamic nature of forest land ownership.

Further analysis showed that about 25 percent of the respondents who obtained a portion of the 1960 base acres after 1967 reported first acquiring woodland before 1967, which indicates they added to an existing forest base. More important, perhaps, is the indication that a large proportion of the different

owners had *not* owned woodland before. This highlights the never-ending task facing Extension Service and State forestry personnel responsible for educating and encouraging owners in the practice of proper forest management.

Some Properties Larger, Some Smaller

The number of forest acres owned has been demonstrated to be an important variable relative to owner interest in timber harvest and forest management (Webster and Stoltenberg 1959). When the same owner owns all or even part of a property in 1979, that property is twice as likely to contain the same forest acreage as in 1967 than when different owners are involved—40 percent vs. 21 percent (table 2). Even so, only 40 percent of the same owners were found to have the same amount of forested acreage in the two periods. Consequently, stability of tenure does not necessarily mean stability of forest ownership, although it tends to. A different owner is far more likely to report reduced acreage than is the same owner—59 percent vs. 39 percent. On the other hand, the proportion reporting increased forest acres is about the same for the two owner classes—19 percent vs. 21 percent.

For those properties that have the same owner and are now smaller and less than 50 acres, 62 percent were less than 50 acres in 1967 (table 3). Of those properties with different owners, only 37 percent were already less than 50 acres.

We did not find that resident or nonresident status had much influence on change in size class of holding. Resident holdings were as apt to be smaller in 1979 compared to 1967 as were nonresident holdings. Actually, a higher proportion of properties with the same resident owner were reported to have less forest acreage than when the same nonresident retained an interest. Properties with different owners exhibited similar tendencies. It would seem then, that nonresident ownership does not necessarily lead to increased division of forest properties.

For both resident and nonresident properties, we saw significant increases in the number in the under 35-acre size classes (table 4). Beyond this, the nonresident situation has not changed much except for the addition of one large property. However, for residents, there seems to be a decrease in the intermediate-size forest holdings and a significant increase in the 150- to 599-acre class as well as in the smaller size classes.

Finally, though the number of small properties has increased substantially, the proportion of acreage in larger holdings has been maintained. Large tracts tend to be cheaper to treat per acre. The enlargement of some properties may offset the division of others to allow the delivery of forestry expertise at a reasonable cost. In this way, a high level of management can be provided on an adequate acreage to supply enough timber to maintain a stable real price for forest products. If foresters were to focus their efforts on the larger forest holdings, the stability in this class, especially of nonresident owners, may favor intensive forest management investment.

Division and Augmentation

There were 178 undivided properties in 1979—that is, the entire 1967 area was controlled by only one owner in 1979, not necessarily the same person. Five of these reported having no forested acreage; two of the five had less than 10 acres of forest in 1967, three were between 40 and 60 acres. Also, four 1967 ownerships were consolidated into two ownerships by 1979.

Forty of the 1967 properties were divided and had more than one owner by 1979. By then, 113 holdings had a portion of the original 1967 acreage, but 15 of these reported having no forested acreage. However, only one complete 1967 property had two new owners both reporting no forest acreage. Also only 24 (11 percent) of the 1967 properties were divided where all the new forested holdings were less than the original size.

One hundred seventy-three (64 percent) of the 1979 forest holdings were undivided 1967 properties:

- Seventy-three had the same forest acreage.
- Fifty-six had less forest acreage.
- Forty-four had more forest acreage.

Ninety-eight (36 percent) of the 1979 forest holdings were divided 1967 properties:

- One had the same forest acreage.
- Eighty-three had less forest acreage.
- Fourteen had more forest acreage.

For the undivided holdings, most that were smaller changed less than 20 acres, most that increased changed by more than 50 acres (table 5). However, much of the change in acres owned was a muddling within a size class and not many large, undivided holdings were reported to be much smaller units in 1979. Not many of the smaller properties became much larger either through purchase, reforestation, or natural growth. Many of those that added 50 or more acres were fairly large to begin with.

To summarize, in this dynamic arena of land exchange it appears that a fixed land base is continually divided among more and more owners. But, both division and augmentation take place in a confounding manner. To supply professional service to the original study acreage, many more owners would have to be contacted. If this were done, however, a much larger amount of land would be serviced. Because there is a larger proportion of tracts in the less than 35-acre size class and a decrease in the proportion in the 35- to 150-acre class, we may expect higher forestry servicing costs per acre. In the face of these shifts, it is comforting that some tracts become part of larger properties. The confounding part is that simple statistics tell us little. For example, average size of holding continues to increase. However, even though there were many more smaller holdings in 1979, not much of the change was caused by drastic shifts from a larger to a smaller size. There are more properties, and much more acreage, in holdings of 150 acres or over in 1979 compared to 1967. And, the proportion of the 1979 acreage in large ownerships has not been diminished through division or change. These trends suggest stable forestry servicing costs.

TIMBER HARVEST ATTITUDES

A major concern about NIPFL owners is their attitude or intentions about harvesting timber. It has been demonstrated that at any particular time a rather consistent proportion of owners indicate they will not harvest their timber. In 1967, Stone found that individual owners were not consistent in intentions over time; and he hyphothesized that most of the timber on nonindustrial private forests would probably be available for harvest for one reason or another. Our study confirms this inconsistency in attitude and action.

1967 Attitudes

From our analyses of the original interview schedules completed in 1967, we estimated 65 percent of the owners controlling 78 percent of the acres did not oppose timber harvests. Seventy percent of the residents were not opposed to timber harvest, but only 50 percent of the nonresidents felt this way. Thus, 35 percent of the owners controlling 22 percent of the acres, said they would not harvest their timber. Seven percent of the residents and 8 percent of the nonresidents would not harvest because the owner was incapacitated or the land was in an inactive status.

1979 Attitudes

In 1979, we asked owners if they planned to harvest in the next 10 years, sometime in the future, or never; we also asked if they had cut timber since 1967. About two-thirds of our 1979 respondents indicated they were not opposed to harvesting timber; 33 percent, controlling about 16 percent of the forest acreage, were opposed. These results are similar to those found in the 1967 survey and in many other nonindustrial landowner studies. These proportions held for both resident and nonresident owners.

Changing Attitudes

For many properties, the attitude of the owner toward timber harvest was different from that in 1967 (table 6). Where a different owner was involved, we contrasted the position of the former property owner with that of the current owner.

Thirty-five percent of the responding 1979 resident owners had a change in attitude about timber harvest. Of these, 43 percent changed to positive and 57 percent changed to a negative attitude. For those with a positive attitude now, half were different resident owners of property previously owned by a resident. For those with a negative attitude, 37 percent were the same 1967 owners.

Quite a different pattern is shown by nonresident owners. Forty-five percent had a change in attitude. However, 60 percent of the shifts were to a positive attitude. This change was evenly divided between different owners of property formerly held by nonresidents and different nonresidents who had obtained property from a 1967 resident owner. These responses show that when resident-held property shifts to nonresident status, the timber is still probably available for harvest.

Harvest Actions

Attitudes or intentions are one thing, positive actions are something else. Not all expressed intentions are a whimsy of the moment. As indicated by reasons given for not harvesting, when owners record their harvest plans they probably consider the size, quality or amount of timber they have available, their current use of the land, the size of the property, and perhaps proximity of the timber to a home or a cabin. Some owners, when asked to make a hypothetical decision about timber harvesting, may be concerned about slash or may believe that appearance of an area would be drastically changed by logging.

But what has actually happened? We found that 11 ownerships with definite negative harvest attitudes in 1967 had harvested timber by 1979. Of the 11 properties, only two had the same owners in 1979 as in 1967. Five said they had cut because they needed the money. In addition, three inactive ownerships whose owners indicated their timber was unavailable in 1967 had new owners by 1979 who had harvested. Quite obviously, from this sample, different owners are an overwhelming factor as timber cutting prospects. I feel this confirms Stone's perception of timber supply from NIPF ownerships. At one time or another, most timber on these ownerships will be available, and the portion unavailable over a long time period is much smaller than many believe it to be. This has important implications for estimates of national timber supply from NIPFL holdings, and is especially important in assessing timber availability over the long run for industrial development projects being considered by forest industry firms.

Improvement Cut Attitudes

In 1979, we asked owners about their interest in a whole-tree thinning where skidding and chipping would remove the entire tree and leave a slash-free residual stand, as well as generally improve the wildlife habitat, timber quality, and growth. The most interesting contrast in attitudes involves nonresidents. A whopping 63 percent of the nonresident owners holding negative attitudes towards timber harvest said they would consider a whole-tree thinning. Only 21 percent said they would not consider any kind of cut, and 16 percent did not answer the question. Thus, slash or esthetics is an important deterrent to harvesting. Resident owners held a quite different attitude towards an improvement cut. Of those owners opposed to timber cutting, only 23 percent showed an interest in whole-tree thinning; 70 percent did not. Seven percent did not answer the question.

An additional contrast between residents and nonresidents shows that, of those having positive harvest attitudes, 70 percent of the residents and 87 percent of nonresidents would be interested in the whole-tree thinning concept. Thus, while a majority of both groups expressed at least an interest in the concept, proportionately more of the nonresidents did. These data suggest that the shift of property to nonresident status may not preclude commercial timber production as many foresters perceive, even though nonresidents may be most concerned about non-consumption forest uses. Many of those with a positive response toward improvement thinning might have been motivated to improve wildlife habitat or wood lot appearance.

OTHER OWNER ATTITUDES

Reason for Owning Forest Land

Reasons for owning forest land are reasonably consistent for the three study periods (table 7). This pattern, again, seems to follow that of many landowner studies. The proportion of owners holding a particular attitude changes little. But, the primary reason for owning may change for a specific owner or property.

In 1979, resident owners more often cited recreation as an important reason for owning forest land than they did in the past. It may be that recreation replaced the more mundane "residence" as a reason. However, this shift to recreation did not seem to influence the residents' attitude toward timber harvest, which remained consistent from 1967 to 1979. The increase in the proportion of both resident and nonresident owners who said farm or domestic use of timber was important may reflect their increased use of firewood.

Owners with Changed Attitudes

Fifty-eight of the 1967 properties were held by 70 owners in 1979 that gave a different principle reason for holding their woodland than owners of the same property had given in 1967. Of these 70 owners, 46 were different owners and 24 were the same owners as in 1967. Thus, while change in attitude may often be attributed to different owners, a significant number of owners change their outlook over time.

When we considered only properties where a change in attitude was documented, we found that, for resident owners, recreation and home use of products accounted for major increases (table 8). Not many owners changed to favor timber production. Recognize, for example, that properties whose nonresident owners said recreation was most important in 1967 (42 percent) had owners in 1979 with a different reason for owning even though the proportion citing recreation was about the same in both years. This table simply confirms that while many properties have owners that now say recreation is the most important reason for owning, a significant proportion have shifted from recreation to a different reason.

Recreation has become a more important reason for owning forest land. Forty percent of this change to recreation came from properties whose owner listed "part of residence" as the primary reason for owning forest land in 1967, 21 percent came from the "investment" category, 18 percent each came from "timber" and "inactive," and 4 percent came from "farm or domestic use." New owners account for the

overwhelming portion of this shift to recreation. For those properties shifting from recreation in 1967 to a new reason for owning category in 1979, we found that 65 percent had new owners and 45 percent had changed from a nonresident owner to a resident owner.

Of those ownerships that had changed from timber production as most important in 1967, 62 percent shifted to recreation, most had different resident owners. Only four ownerships shifted to timber production as the most important reason in 1979, two came from recreation.

Reasons for Harvesting

Residents consistently cite mature timber and the need for money as important reasons for harvesting timber (table 9). However, in 1979, thinning, salvage and own use of the wood increased as reasons, possibly because of the emphasis on cutting firewood to supplement or replace fossil fuel. In 1960 and 1967, several individuals harvested to provide wages for themselves or family members, but this was not listed as an option in 1979. Not many nonresidents harvested timber between 1967 and 1979.

Reasons for Not Harvesting

Main reasons given for not harvesting were immature timber, small volume or small area, with esthetics and scenery also important for both residents and nonresidents (table 10). Again, the reason given as most important changes with properties and owners over time. Saving for own use has increased as a reason for not selling timber and is probably influenced by the high cost of fossil fuel.

OWNER CHARACTERISTICS

Age

Age is a variable often used in NIPFL studies to predict attitude or performance relative to forestry projects. Age distribution shows an increase in the 25- to 44-year age class from 1960 to 1967 for both residents and nonresidents, but both classes were nearer to the 1960 level again in 1979 (table 11). The percent of nonresidents in the 65 and over class dropped somewhat from 1960 to 1967 but increased again by 1979. Generally the 1979 levels were closer to the 1960 proportion. Nonresident owners were slightly younger, on the average, than resident owners in all study years. Younger resident owners generally owned smaller forested tracts than older owners (table 12).

Occupation

Occupation trends showed slightly fewer farmers in 1979 (table 13). Resident professional and executive owners increased slightly, but nonresidents decreased a bit. Both resident and nonresident wage earners continued to increase as they had in 1967. The proportion of retired residents was stable for all three periods, but nonresident retirees doubled from 1967 to 1979.

Professional/executives and farmers owned larger tracts than those in other occupations on the average, but resident wage earners and retirees were well represented in the 75- to 149-acre size class.

SUMMARY

Information from three time periods gives some insight into how a land base in Michigan's Upper Peninsula has been divided and augmented over time and how private forest landowners react to timber harvesting opportunities. There has been a concern that owners, especially nonresidents, may have non-timber objectives for forest land ownership that could influence the availability of timber for harvest, and that division of holdings will lead to the development of non-economic-sized forest tracts. Our study confirms that while the proportion of owners favoring or opposing timber harvest is reasonably consistent at any particular time, it is not the same timber tracts for which owners hold a particular view. New owners hold different attitudes or the same owners have changed their attitude as their circumstances or perceptions change. In this case, it seems that resident owners were more important than nonresidents in shifting ownership emphasis to recreation as a reason for owning timberland.

The stable proportion of ownerships in the larger size classes and the shifting attitudes and actions of owners relative to timber harvesting indicate that a significant acreage may be continuously available for efficient management. The increase in the number of smaller properties was not a result of drastic change from larger to smaller tracts.

The increasing proportion of nonresident owners, while not necessarily as ominous from the timber harvesting standpoint as some have perceived, certainly means management agencies may need to shift their contact methods to accommodate this change.

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Table 1.—*Number of owners, acres of forest land owned, and average size of holding by size class, residency status and year*

Size class (acres)		Resident			Nonresident			Total					
								1960		1967		1979	
		1960	1967	1979	1960	1967	1979	Number	Percent	Number	Percent	Number	Percent
1–9	No.	7	6	27	3	4	9	10	5.1	10	4.5	36	13.3
	Acres	37	30	128	24	32	57	61	.3	62	.2	185	.5
	Ave.	5	5	5	8	8	6	6		6		5	
10–34	No.	30	29	48	9	11	27	39	19.8	40	18.0	75	27.7
	Acres	649	588	908	176	206	531	825	4.0	794	2.7	1,439	3.9
	Ave.	22	20	19	19	19	20	21		20		19	
35–74	No.	59	59	44	15	21	24	74	37.5	80	36.0	68	25.1
	Acres	2,753	2,831	2,053	626	943	1,071	3,479	16.6	3,774	12.7	3,124	8.4
	Ave.	48	48	47	44	45	45	47		47		36	
75–149	No.	41	43	31	8	14	12	49	24.9	57	25.7	43	15.8
	Acres	4,168	4,204	3,062	754	1,312	1,233	4,940	24.3	5,516	18.6	4,295	11.5
	Ave.	102	98	99	91	94	103	101		97		100	
150–599	No.	21	23	36	2	6	6	23	11.7	29	13.1	42	15.5
	Acres	4,625	5,418	9,689	448	1,338	1,497	5,073	24.9	6,756	22.8	11,186	30.1
	Ave.	220	236	269	224	223	250	221		233		266	
600+	No.	1	5	5	1	1	2	2	1.0	6	2.7	7	2.6
	Acres	4,060	10,750	10,542	2,000	2,040	6,440	6,060	29.8	12,790	43.1	16,982	45.6
	Ave.	4,060	2,150	2,108	2,000	2,040	3,220	3,030		2,132		2,426	
Total	No.	159	165	191	38	57	80	197	100.0	222	100.0	271	100.0
	Acres	16,310	23,821	26,382	4,028	5,871	10,829	20,338	100.0	29,692	100.0	37,211	100.0
	Ave.	102	144	138	106	103	135	103		133		137	

Table 2.—*Number of owners by residency status, tenure, and comparative size of holding, 1967–1979*

Owner status[1]	Number of owners		Size of holding in 1979					
			Larger		Same		Smaller	
	1967	1979	Number	Percent	Number	Percent	Number	Percent
Different owners								
R-R	50	75	15	20	14	19	46	61
N-N	22	27	4	15	8	30	15	55
N-R	11	14	2	14	3	21	9	64
R-N	31	33	8	24	7	21	18	55
Total	114	149	29	19	32	21	88	59
Same owners								
R	94	94	22	23	35	37	37	40
N	18	18	2	11	13	72	3	17
N-R	8	8	2	25	1	12	5	63
R-N	2	2	—	—	—	—	2	100
Total	122	122	26	21	49	40	47	39
All owners	236[2]	271	55	20	81	30	35	50

[1]R = Resident N = Nonresident.

[2]Of the 1967 owners, 14 retained part of a sudivided property, 12 were residents, 2 were nonresidents.

Table 3.—*Distribution of properties that were smaller in 1979 than in 1967 by current size class, residency status, and tenure*

Owner status[1]	Total		Current size class							
			< 50 acres		50–99 Acres		100+ Acres		50 acres in 1967[2]	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Different owners										
R-R	46	100	40	87	4	9	2	4	9	22
N-N	15	100	14	93	1	7	–	–	8	57
N-R	9	100	8	89	1	11	–	–	6	75
R-N	18	100	14	78	2	11	2	1	5	36
Total	88	100	76	86	8	9	4	5	28	37
Same owners										
R	37	100	20	54	8	22	9	24	13	65
N	3	100	3	100	–	–	–	–	2	67
N-R	5	100	5	100	–	–	–	–	3	60
R-N	2	100	1	50	–	–	–	–	–	–
Total	47	100	29	62	9	19	0	19	18	62
All owners	135	100	105	78	17	12	13	10	46	44

[1]R = Resident N = Nonresident.

[2]Column show percent of ownership currently less than 50 acres.

Table 4.—*Number of owners and acres of commercial forest land owned by size class and residency, 1967 and 1979*

Size class	Resident				Nonresident			
	1967		1979		1967		1979	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
OWNERS								
1–9	6	3	27	14	4	7	9	11
10–34	29	18	48	25	11	19	27	34
35–74	59	36	44	23	21	37	24	30
75–149	43	26	31	16	14	25	12	15
150–599	23	14	36	19	6	10	6	8
600+	5	3	5	3	1	2	2	2
Total	65	100	191	100	57	100	80	100
ACRES								
1–9	30	([1])	128	([1])	32	([1])	57	1
10–34	588	2	908	3	206	4	531	5
35–74	2,831	12	2,053	8	943	16	1,071	10
75–149	4,204	18	3,062	11	1,312	22	1,233	11
150–599	5,418	23	9,689	38	1,338	23	1,497	14
600+	10,750	45	10,542	40	2,040	35	6,440	59
Total	23,821	100	26,382	100	5,871	100	10,829	100

[1]Less than 0.5 percent.

Table 5.—*Distribution of the undivided properties by amount and direction of change from 1967 to 1979*

(In percent of ownerships)

Direction of change	Amount property increased or decreased (acres)							
	< 10	11–19	20–29	30–39	40–49	50–99	100+	Total
Decrease	14	18	7	5	3	6	3	56
Increase	9	7	4	1	1	9	13	44
Total	23	25	11	6	4	15	16	100

Table 6.—*Distribution of owners response to timber harvest attitude by residency status and change since 1967*

(In percent of owners)

Owner response	Resident	Nonresident	All owners
Changed attitude	35	45	38
To positive	43	60	18
To negative	57	40	19
No change	65	55	62
Positive	81	71	48
Negative	19	29	14
All owners	100	100	100
Positive	68	66	67
Negative	32	34	33

Table 7. *Primary reason owners hold forest land by residency status and study date*

(In percent of owners)

Reason for owning	Resident			Nonresident		
	1960	1967	1979	1960	1967	1979
Domestic or farm use	17	16	22	5	3	8
Part of residence	33	26	20	0	3	3
Investment	12	12	9	21	16	22
Recreation use	23	31	40	66	57	58
Timber production	4	10	6	0	2	3
Other	11	5	3	8	19	5
Total	100	100	100	100	100	100

Table 8.—*Distribution of properties whose owners had a different reason for owning in 1979, by reason for owning residency status*

(In percent of owners)

Reason for owning	Resident		Nonresident		All owners	
	1967	1979	1967	1979	1967	1979
Domestic or farm use	2	19	–	14	1	17
Part of residence	41	23	–	–	30	16
Investment	16	14	26	27	19	40
Recreation use	10	40	42	41	19	40
Timber production	16	4	–	9	11	6
Inactive	16	–	32	9	20	3

Table 9.—*Primary reason for harvesting or selling timber by study date and residency status*

(In percent of owners)

Reason for harvest	Year		
	1960	**1967**	**1979**
RESIDENTS			
Mature timber	26	33	25
Thinning	0	6	17
Salvage	0	2	18
Money	45	31	18
Clear land	2	7	8
Wages/price	21	17	0
Taxes/own use	0	2	13
Other	6	2	0
NONRESIDENTS			
Mature timber	0	33	33
Thinning	0	0	11
Salvage	0	0	0
Money	0	67	33
Clear land	0	0	22
Wages/price	0	0	0
Taxes/own use	0	0	0
Other	0	0	0

Table 10.—*Reasons owners do not harvest or sell timber by residency status and study date*

(In percent of owners)

Reason for not harvesting[1]	Residents			Nonresidents		
	1960	**1967**	**1979**	**1960**	**1967**	**1979**
1	55	54	39	54	33	30
2	0	1	15	0	2	7
3	10	11	0	3	17	7
4	2	3	0	0	2	2
5	6	3	6	8	6	2
6	1	14	15	3	29	26
7	10	5	15	5	2	19
8	17	10	9	27	8	7

[1] 1 - Immature timber, small area, or insufficient volume.
2 - No market, low price, poor quality.
3 - Property in unsettled estate, for sale, never asked.
4 - Distrust loggers, opposed to logging.
5 - Incompatible with other uses, especially hunting.
6 - Esthetics, spoil scenery, seentimental.
7 - Saving for retirement, for children, own use.
8 - Other (no time, no reason, need advice).

Table 11.—*Distribution of respondents by age class, study date, and residency*

(In percent of owners)

Year	Age class				
	Under 25	25–44	45–64	65+	All
RESIDENT					
1960	1	18	53	28	100
1967	1	25	49	25	100
1979	2	20	47	31	100
NONRESIDENT					
1960	0	24	54	21	100
1967	2	32	52	14	100
1979	3	25	55	17	100

Table 12.—*Distribution of respondents by age class, size class, study date, and residency status*

(In percent of owners)

Size class of property	Age class							
	<25		25 – 44		45 – 64		65+	
	1967	1979	1967	1979	1967	1979	1967	1979
RESIDENT								
1–9	0	4	40	41	20	41	40	14
10–34	3	6	46	27	40	53	11	19
35–74	0	0	24	18	45	42	31	39
75–149	2	0	13	12	55	46	30	42
150–599	0	0	19	15	62	52	19	33
600+	0	0	20	0	60	50	20	50
NONRESIDENT								
1–9	0	0	40	22	60	56	0	22
10–34	0	9	40	26	40	52	20	13
35–74	6	0	13	25	69	69	12	6
75–149	0	0	46	29	39	14	15	57
150–599	0	0	40	20	60	80	0	0
600+	0	0	0	0	0	0	100	0

Table 13.—*Distribution of respondents by occupation, residency status, and study year*

(In percent of owners)

	Resident			Nonresident		
	1960	1967	1979	1960	1967	1979
Farmer	10	11	7	3	3	0
Professional	18	18	23	35	38	35
Wage earner	29	31	34	24	28	35
Retired	24	25	26	8	12	24
Recreation	8	7	7	19	14	6
Estate	2	1	1	3	2	0
Other	8	7	2	8	2	0
Total	100	100	100	100	100	100

Carpenter, Eugene M.
Ownership change and timber supply on nonindustrial private forest land. Res. Pap. NC-265. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 14 p.

Presents trends in private forest land ownership in Michigan's Upper Peninsula. Describes how changes in owners, their intentions, and their actions might affect the area's timber supply with implications for the national timber supply.

KEY WORDS: Private owner characteristics, timber harvest attitudes, private owner tenure, forest subdivision, aggregation, harvest intentions and actions.

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Prescribed Burning for Oak Savanna Restoration in Central Minnesota

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PRESCRIBED BURNING FOR OAK SAVANNA RESTORATION IN CENTRAL MINNESOTA

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Prior to European settlement, oak savannas dominated the prairie-forest ecotone in Minnesota (Drew 1973, McAndrews 1966, Pierce 1954) as well as in several other midwestern States (Cottam 1949, Curtis 1959, Finley and Potzger 1951-52, Potzger *et al.* 1956, Rohr and Potzger 1952, Stroessner and Habeck 1966). Now, however, oak savannas are rare because of agricultural land clearing, cattle grazing, and fire suppression (Curtis 1959). The purpose of this study was to evaluate an effort to restore oak savanna through prescribed burning.

The presettlement role of fire in the forest-prairie transition zone was twofold. Occasionally, fires spread from the prairie into the oak forests, killing all but the largest trees, thereby creating savannalike conditions (Curtis 1959). Frequent, low-intensity fires also maintained existing savannas (Curtis 1959, Drew 1973), presumably by reducing the number of oak sprouts and seedlings that survived or that made it into the overstory and by favoring the growth of herbaceous species that require high light levels. When the forest-prairie transition zone was settled, fires were suppressed and the savannas were quickly taken over by young oak trees and brush, which often resulted in a dense oak forest within 25 to 30 years (Curtis 1959).

Today, prescribed fire is being used at the Cedar Creek Natural History Area (CCNHA) in central Minnesota in an attempt to restore existing oak forests to oak savannas (Irving 1970), like those that occupied much of the area in presettlement times (Pierce 1954). The concept is that prescribed fire can be used as a restoration management tool to reduce oak overstory density, reduce shrub and sapling height and density, and encourage grasses and forbs. The objective of this study was to compare the vegetation on areas at CCNHA that had been subjected to various prescribed burning regimes since 1964. The results should be of use to land managers interested in restoring similar areas to oak savanna as well as to land managers using prescribed fire in oak forests for other purposes, such as range improvement.

STUDY AREA

The Cedar Creek Natural History Area is located approximately 32 miles north of St. Paul, Minnesota, and has a temperate, continental climate. The topography ranges from gently rolling to flat. Two soil series, Sartell and Zimmerman, dominate the prescribed burning area. Both series are sandy Entisols characterized by low fertility and high permeability (Grigal *et al.* 1974). According to the General Land Office survey notes of 1854, most of the uplands at CCNHA supported scattered, scrubby northern pin oak (*Quercus ellipsoidalis*)[1] and bur oak (*Q. macrocarpa*) (Pierce 1954). These same two species dominate the wooded sites in the prescribed burning area today, but in the unburned control sites they now form a closed-canopy oak forest.

METHODS

A prescribed burning program was initiated in 1964 on a portion of CCNHA (Irving 1970). The area was divided into blocks, some of which were subjected to varying prescribed burning schedules and some of which were maintained as unburned controls. Burns were conducted in April or May between the disappearance of snow and the leafing out of the oaks. Preferred burning conditions were 30 to 40 percent relative humidity, steady 8 to 12 mile per

[1]*Nomenclature follows Gleason and Cronquist (1963).*

Table 1.—*Prescribed burning schedule, block size, and number of plots for blocks included in this study*

Block number	Total[1] size	Planned[2] burning schedule	Actual number of burns	First burn	Plots
	Acre			*Year*	*Number*
1a	6.5	2 yrs burn/2 yrs no burn	7	1967	3
1	33.6	4 yrs burn/2 yrs no burn	10	1964	6
3	28.7	Annual burns	14	1965	11
4	50.4	Annual burns	16	1965	19
5	39.5	3 yrs burn/3 yrs no burn	9	1965	15
6	20.0	2 yrs burn/1 yr no burn	10	1966	9
8	70.6	2 yrs burn/2 yrs no burn	7	1967	14
Control	--	Unburned	0	--	11

[1]Some units included old fields, which were excluded from this study. The number of plots per block is proportional only to the wooded area.

[2]In some years burning was not possible because of lack of suitable burning conditions. Consequently, actual burning schedules may deviate slightly from planned burning schedules (see White (1981) for a more detailed description).

hour winds, and constant wind direction (Irving 1970). These burning conditions were chosen to minimize the risk to people and structures and to decrease the probability of abrupt, undesirable effects on the existing plant communities.[2] Spring burns in Minnesota are often less severe than fall burns because in the spring high duff moisture limits available fuel and the downward transfer of heat, and because rapid growth of plants following spring fires reduces nutrient losses via leaching (McColl and Grigal 1975). Actual weather conditions at the time of each burn are on file at CCNHA.

Quantitative information on fire behavior at CCNHA is limited to studies on blocks 3, 4, and 6 (table 1). Oak litter consumption ranged from 0.04 (Wick 1966) to 0.67 tons per acre (Rimmel 1979), with percent consumption ranging from 9 percent (Wick 1966) to 72 percent (Rimmel 1979). Total consumption (litter, herbaceous, 1 hour timelag fuels) ranged from 0.62 to 1.00 tons per acre, with percent consumption ranging from 44 to 66 percent (Rimmel 1979). Rate of spread ranged from 8.5 (Wick 1966) to 55.1 feet per minute (White 1981).

Seven burning blocks and a control were included in this study (table 1). Excluded blocks were dominated by abandoned agricultural fields, occurred on rare soil types, or had very irregular burning schedules. Burning schedules varied according to the number of consecutive years of burning and the number of years between burns. Although blocks 1a and 8 had the same burning schedule, as did blocks 3 and 4, each block was considered a separate entity for analysis because some blocks occasionally were not burned on schedule due to unacceptable burning conditions. Also, although it was assumed that blocks were similar prior to initial burning, preburn information was not available.

Plot locations within blocks were established by stratified random sampling. Strata were defined by soil mapping unit, the only potential source of variation that was already mapped. This system ensured that all possible combinations of burning blocks and soils that occurred on the study area were sampled. Plot locations within each stratum were chosen by randomly generated coordinates at the sampling intensity of approximately one plot per 2.5 acres.

Each plot consisted of one 1,075 square foot circle and one 269 square foot circle, both centered on the same point, and ten 2.7 square foot circles distributed systematically within the 1,075 square foot circle (fig. 1). In the 1,075 square foot circle, all woody stems ≥ 2 in d.b.h. were recorded by species, d.b.h., and age at breast height. In the 269 square foot circle, all woody species with stems ≥ 0.4 in diameter at ground level (d.g.l.) and <2 in d.b.h. were recorded by percent cover. In each of the ten 2.7 square foot circles, woody species with stems <0.4 in dgl and all nonwoody species present were recorded. The number of 2.7 square foot circles (out of 10 possible) in which a species was present was used to calculate percent frequency for each species in each plot. Nonvegetation variables were recorded for the plot as a whole and included prescribed burning block, soil series, elevation, and slope. Data on the 1,075 square foot and 269 square foot plots were collected from late summer through early winter in 1978 and data on the 2.7 square foot plots were collected in June 1979. A preliminary sample of the 2.7

[2]*Frank D. Irving, Professor, University of Minnesota; personal communication.*

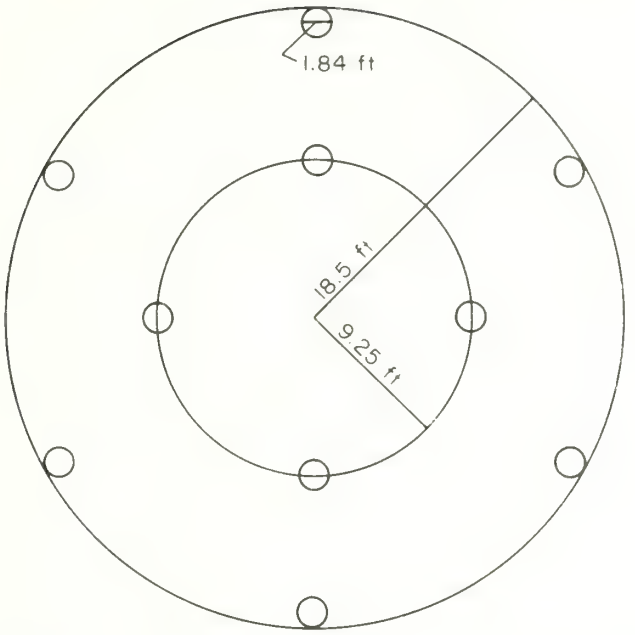

Figure 1.—*Plot design. The largest circle is 1,075 square feet, the inner circle is 269 square feet, and each of the smallest circles is 2.7 square feet.*

square foot plots taken in August 1978[3], indicated that species composition was similar regardless of whether sampling was done in June or August. The 1979 sampling occurred at the end of the burning cycle for blocks 1, 5, 6, and 8 but at the end of the rest period for block 1a (table 1). Blocks 3 and 4 are burned annually. For the sake of simplicity, data collected in the 2.7 square foot circle will be referred to as understory data, those in the 269 square foot circles will be referred to as shrub data, and those in the 1,075 square foot circles will be referred to as overstory data.

Prior to analysis, the number of understory species was reduced from 123 to 50 using the SCREEN program (Grigal and Ohmann 1975), which ranks each species on the basis of five criteria: occurrence over all plots, average frequency per plot, ratio of computed standard deviation to predicted standard deviation, information content based on species presence or absence by plot, and relative contribution of each species in the calculation of interstand distance in ordination space. Only a few species were recorded in the shrub and overstory plots; those occurring in $\geq$10 percent of the sites were included in subsequent analyses.

Data analysis involved two approaches. First, the relations between individual species and nonvegetation variables were analyzed with a nonparametric Kruskal-Wallis test (Conover 1971). This test was used because most of the species data were not normally distributed and could not be transformed to normality and because the nonvegetation variables were either nonordinal, categorical (prescribed burning block, soil series), or easily categorized (elevation, slope). The relations of the understory and shrubs to the overstory were analyzed using Spearman's Rank Correlation Coefficient, r_s (Siegel 1956).

Second, the plant community as a whole was analyzed in relation to the same nonvegetation variables. One approach was to group sites on the basis of similarity in species composition and abundance by using Orloci's (1967) agglomerative cluster analysis technique. Once groups of sites were formed, relations to the nonvegetation variables were investigated using contingency table analysis. This analysis determined whether or not sites with similar nonvegetation characteristics tended to group together on the basis of species composition and abundance. The other approach involved reciprocal averaging (Hill 1973), an ordination technique made available through the ORDIFLEX program by Gauch (1977). Reciprocal averaging (RA) places sites in relation to one another on the basis of similarity in terms of species composition and abundance. It differs from cluster analysis in that each site can be seen in terms of its relation to all other sites and no groups are automatically formed. Relations to nonvegetation variables were analyzed by inspecting the RA distribution to determine if sites with similar nonvegetation characteristics tended to occur together.

RESULTS

Individual understory species occurred in 5 to 94 percent of the plots while average frequency values per plot ranged from 1 to 77 percent. Shrub species were less widespread, their occurrence ranging from 10 to 15 percent of the plots, with average cover values per plot ranging from less than 1 percent to 2 percent. In the overstory, pin oak occurred in 60 percent of the plots with an average density of 127 stems per acre and an average basal area of 52 square feet per acre, while bur oak occurred in only 34 percent of the plots with an average density of 40 stems per acre and an average basal area of 13 square feet per acre.

In the understory, 36 species (72 percent of the total) had significantly different average frequen-

[3]*Unpublished data on by Author.*

Table 2.—*Relations of species to blocks as indicated by a Kruskal-Wallis test. Table entries under each block are average frequencies (understory plots), average cover (shrub plots), and density and basal area (overstory plots). P indicates the probability that values were distributed randomly among blocks*

		Blocks							
Species	**P**	**1a**	**1**	**3**	**4**	**5**	**6**	**8**	**Control**
Understory plots									
Agropyron repens	0.001†	0	22	0	4	0	0	1	0
Ambrosia psilostachya	.002†	7	20	32	56	45	40	27	4
Amorpha canescens	.003†	0	3	9	3	4	19	9	0
Amphicarpa bracteata	.000†	93	92	32	19	25	8	47	41
Andropogon gerardi	.000†	0	12	44	5	26	26	4	5
Andropogon scoparius (*Schizachyrium scoparium*)	.071	0	0	12	7	3	14	3	0
Anemone spp.	.006†	0	0	2	1	3	11	4	0
Artemisia ludoviciana	.003†	0	0	20	9	8	13	17	0
Asclepias spp.	.008†	7	0	13	11	8	12	3	0
Bromus inermis	.000†	40	0	1	0	0	0	0	0
Calamagrostis canadensis	.467	30	0	4	4	5	0	2	0
Calamovilfa longifolia	.001†	0	0	5	20	8	27	6	0
Carex spp.	.028†	37	17	33	24	25	10	22	44
Celastrus scandens	.001†	7	0	0	8	5	1	23	2
Chenopodium spp.	.177	0	0	3	2	1	0	0	6
Comandra richardsiana	.000†	0	2	26	3	23	24	24	0
Coreopsis palmata	.243	3	5	11	2	3	10	11	2
Corylus americana	.000†	0	7	18	11	13	2	29	37
Cyperus spp.	.001†	53	83	83	78	85	90	86	40
Fragaria virginiana	.583	0	3	6	5	9	3	6	5
Galium boreale	.000†	77	17	0	2	0	0	0	9
Helianthemum bicknellii	.001†	0	0	6	21	19	6	4	0
Helianthus laetiflorus	.213	0	2	20	5	5	3	6	4
Lathyrus venosus	.000†	3	32	0	9	0	40	0	2
Lespedeza capitata	.147	0	2	3	6	6	0	0	0
Lithospermum carolinense	.001†	0	0	1	3	11	1	4	0
Panicum oligosanthes	.002†	10	3	9	25	14	9	6	0
Panicum perlongum	.008†	0	0	1	12	6	10	2	0
Panicum cf. *praecocius*	.004†	0	0	12	23	14	13	8	2
Parthenocissus vitacea	.000†	40	38	14	21	25	6	44	65
Physalis virginiana	.000†	0	2	6	28	13	7	8	0
Poa spp.	.034†	40	17	15	31	15	7	4	16
Prunus cf. *virginiana*	.022†	0	0	1	2	3	0	6	7
Quercus ellipsoidalis	.142	3	13	23	32	17	23	21	21
Quercus macrocarpa	.027†	0	0	0	2	5	4	11	1
Rhus glabra	.010†	0	0	2	13	6	13	8	3
Rhus radicans	.001†	7	28	13	6	23	20	62	6
Rosa arkansana	.254	0	0	6	5	3	11	4	1
Rubus spp.	.104	10	15	18	6	9	0	1	5
Scutellaria parvula	.012†	0	0	14	6	21	10	14	5
Smilacina stellata	.521	10	20	19	15	17	16	4	10
Solidago spp.	.000†	0	3	26	18	9	7	6	1
Solidago graminifolia	.023†	0	0	8	8	1	7	5	0
Sorghastrum nutans	.001†	0	0	25	11	33	31	9	1
Stipa spartea	.029†	13	23	27	25	35	32	24	6

(Table 2 continued on next page)

Table 2.—*Continued*

Species	P	Blocks 1a	1	3	4	5	6	8	Control
Tradescantia occidentalis	.000†	0	0	14	19	13	4	1	0
Vaccinium angustifolium	.069	0	0	4	1	0	0	0	11
Viola pedata	.006†	3	2	7	9	9	17	4	0
Viola pedatifida	.124	13	3	10	8	9	9	11	1
Viola sagittata	.082	0	0	11	7	7	4	0	2
Shrub plots									
Corylus americana	.000†	0	0	0	1	1	0	3	12
Quercus ellipsoidalis	.003†	0	0	0	1	1	0	0	1
Quercus macrocarpa	.470	0	0	0	1	1	1	1	1
Overstory plots									
Quercus ellipsoidalis density (stems/ac)	.000†	81	250	177	49	40	153	46	353
Quercus ellipsoidalis basal area (ft^2/ac)	.001†	74	91	70	39	30	48	26	113
Quercus macrocarpa density (stems/ac)	.002†	0	0	15	28	40	23	136	7
Quercus macrocarpa basal area (ft^2/ac)	.002†	0	0	4	9	13	9	39	4

† Significant ($P \leq 0.05$)

cies among the blocks (table 2).[4] Only four of those 36 species, however, had their highest average frequency per plot in the control block. Twenty-one of the remaining 32 species had peak average frequencies in the three most frequently burned blocks (3, 4, and 6). However, the range in number of species peaking in any one block was small, with one species peaking in block 1 and nine peaking in block 4.

In the shrub layer, American hazel (*Corylus americana*) peaked in the control block (table 2). Pin and bur oak did not exhibit noticeable peaks. In the overstory, pin oak had its highest density and basal area in the control block whereas bur oak had its highest values in burning block 8 (table 2).

Over half (52 percent) of the understory species had significantly different average frequency values with respect to soil series, with 19 peaking in the Sartell series and seven peaking in the Zimmerman series (table 3). American hazel in the shrub layer and pin oak in the overstory peaked in the Zimmerman series while bur oak in the overstory peaked in the Sartell series. Unfortunately, it was not possible to statistically separate the effects of soil from the effects of fire because not all burning blocks occurred on both soil series.[5] For example, the Sartell series dominated blocks 4, 5, 6, and 8, and the Zimmerman series dominated blocks 1a, 1, 3, and control.

Ten understory species had significantly different average frequency values with respect to elevation, with 6 of those 10 species peaking in the lowest elevation category (table 3). Because the total range in elevation was only 22 feet, elevation probably reflected differences in depth to water table.[6] Only one species, smooth sumac (*Rhus glabra*), showed significant differences with respect to slope, which was divided into four categories: ≤1 percent, >1 percent and ≤2 percent, >2 percent and ≤3 percent, and >3 percent. Given the very limited topographic variation at CCNHA, this result was not surprising.

The relations of understory species and shrubs to the overstory were analyzed using pin oak density and bur oak density separately as representative of

[4]*A nonparametric equivalent to Tukey's multiple comparison tests (Zar 1984) proved to be weak, only showing where the differences between blocks occurred for less than half the species that had significant differences according to the Kruskal-Wallis test. Consequently, peak average values per block were used to make subjective inferences about the block in which a species was most common.*

[5]*This was due to the lack of information on soil series distribution at the time burning blocks were established in 1964 (Frank D. Irving, Professor, University of Minnesota; personal communication).*

[6]*David F. Grigal, Professor, University of Minnesota; personal communication.*

Table 3.—*Relations of all species to soil series and elevation and of understory and shrub species to overstory density. P indicates the probability that values were distributed randomly among soil series or elevation categories*

Species	Soil[1]		Elevation[2]		Correlation (r_s)[c] with overstory density	
	P	*Peak*	*P*	*Peak*	*Quercus ellipsoidalis*	*Quercus macrocarpa*
Understory plots						
Agropyron repens	0.315		0.637		0.10	0.08
Ambrosia psilostachya	.007†	Sartell	.203		−.51†	.12
Amorpha canescens	.106†	Sartell	.036†	M, H	−.14	.19
Amphicarpa bracteata	.016†	Zimmerman	.555		.37†	−.06
Andropogon gerardi	.450		.282		−.01	.01
Andropogon scoparius (*Schizachyrium scoparium*)	.584		.334		−.14	.05
Anemone spp.	.023†	Sartell	.199		−.09	.28†
Artemisia ludoviciana	.471		.527		−.25†	.05
Asclepias spp.	.032†	Sartell	.436		−.27†	−.04
Bromus inermis	.010†	Zimmerman	.001†	L	.09	−.15
Calamagrostis canadensis	.742		.001†	L	−.21†	−.01
Calamovilfa longifolia	.002†	Sartell	.050		−.45†	.08
Carex spp.	.008†	Zimmerman	.021†	L	.06	.00
Celastrus scandens	.070		.049†	H	−.12	.28†
Chenopodium spp.	.145		.150		.14	.22†
Comandra richardsiana	.040†	Sartell	.527		−.01	.18
Coreopsis palmata	.555		.051		.09	.03
Corylus americana	.025†	Zimmerman	.036†	L	.33†	.17
Cyperus spp.	.010†	Sartell	.025†	H	−.17	.07
Fragaria virginiana	.573		.776		−.10	.05
Galium boreale	.000†	Zimmerman	.165		.31†	−.29†
Helianthemum bicknellii	.025†	Sartell	.619		−.42†	−.09
Helianthus laetiflorus	.127		.493		−.20	.13
Lathyrus venosus	.756		.578		.16	−.14
Lespedeza capitata	.698		.178		−.32	−.14
Lithospermum carolinense	.000†	Sartell	.119		−.33†	.11
Panicum oligosanthes	.020†	Sartell	.480		−.35†	.08
Panicum perlongum	.035†	Sartell	.926		−.36†	−.07
Panicum cf. *praecocius*	.011†	Sartell	.833		−.31	.06
Parthenocissus vitacea	.284		.267		.48†	.16
Physalis virginiana	.005†	Sartell	.405		−.47†	.06
Poa spp.	.537		.961		.01	−.04
Prunus cf. *virginiana*	.515		.024†	H	.19	.17
Quercus ellipsoidalis	.300		.877		.09	.18
Quercus macrocarpa	.001†	Sartell	.363		−.26†	.31
Rhus glabra	.025†	Sartell	.310		−.29†	.11
Rhus radicans	.033†	Sartell	.054		.21	.24†
Rhosa arkansana	.357		.916		−.13	.02
Rubus spp.	.010†	Zimmerman	.004†	L	−.02	−.02
Scutellaria parvula	.153		.220		−.23†	.07
Smilacina stellata	.646		.130		−.32†	−.11
Solidago spp.	.353		.866		−.17	.03
Solidago graminfolia	0.685		0.696		−.17	.23†
Sorghastrum nutans	.040†	Sartell	.099		−.36†	−.02

(Table 3 continued on next page)

Table 3.—*Continued*

Species	Soil[1]		Elevation[2]		Correlation (r_s)[3] with overstory density	
	P	*Peak*	*P*	*Peak*	*Quercus ellipsoidalis*	*Quercus macrocarpa*
Stipa spartea	.026†	Sartell	.102		−.20	.05
Tradescantia occidentalis	.958		.931		−.28†	−.02
Vaccinium angustifolium	.002†	Zimmerman	.201		.13	−.10
Viola pedata	.040†	Sartell	.957		−.17	.11
Viola pedatifida	.196		.334		−.17	−.10
Viola sagittata	.999		.027†		−.10	.03
Shrub plots						
Corylus american	.001†	Zimmerman	.244		.18	−.02
Quercus ellipsoidalis	.816		.593		−.12	−.06
Quercus macrocarpa	.329		.839		−.21	.05
Overstory plots						
Quercus ellipsoidalis density (stems/ac)	.001†	Zimmerman	.841		--	--
Quercus ellipsoidlis basal area (ft^2/ac)	.001†	Zimmerman	.926		--	--
Quercus macrocarpa density (stems/ac)	.002†	Sartell	.626		--	--
Quercus macrocarpa basal area (ft^2/ac)	.002†	Sartell	.723		--	--

[1]Where a species was significantly related to soil series, as indicated by a Kruskal-Wallis test, the series in which the species reached its peak value is indicated.

[2]Where a species was significantly related to elevation, as indicated by a Kruskal-Wallis test, the elevation category in which the species reached its peak value is indicated. Elevation categories are as follows: L (low = ≤924 ft), M (medium = 925-929 ft), H (high = >929 ft).

[3]Spearman Rank Correlation Coefficient (r_s).

† Significant ($P \leq 0.05$).

the overstory (table 3). The correlation of density and basal area for each species was very high ($r_s = 0.91$ for pin oak and $r_s = 0.98$ for bur oak); thus, using basal area in addition to density would have been redundant. Twenty-two of the understory species (44 percent of the total) had a significant correlation with pin oak density (17 were negative and five were positive). In contrast, seven species had a significant correlation with bur oak density; six of the correlations were positive. The absolute values of the correlations were typically low, ranging from 0.21 to 0.51.

The plots were clustered by species composition (fig. 2). Five groups of plots were designated (W1 to W5),[7] each of which was composed of plots that were more similar in species composition to other plots in the same group than to plots in other groups. Figure 2 shows that plots from certain burning blocks (e.g., block 8) tended to cluster together, but that in no case did all the plots from any one burning block occur in the same group.

The contingency table analysis showed that the groups formed from cluster analysis were significantly related to fire (burning blocks) and soil series (table 4); that is, certain groups contained more plots representative of one burning block or soil series than would be expected if such plots were distributed randomly among the five groups. Adjusted standardized residuals (Haberman 1973) from the contingency table analysis were used to make qualitative judgments as to which burning blocks or soil series were the most closely associated with which groups. Results indicated that plots from the control block and block 1a tended to occur together in W1, plots from block 8 tended to occur in W2 or W3, plots from block 6 tended to occur in W4, and plots from block

[7]*The choice of what constitutes a group when cluster analysis is applied is arbitrary. I chose five groups that were relatively distinct from one another and that contained enough plots for contingency table analysis. Groups could have been chosen differently, which would have influenced the results of contingency table analysis.*

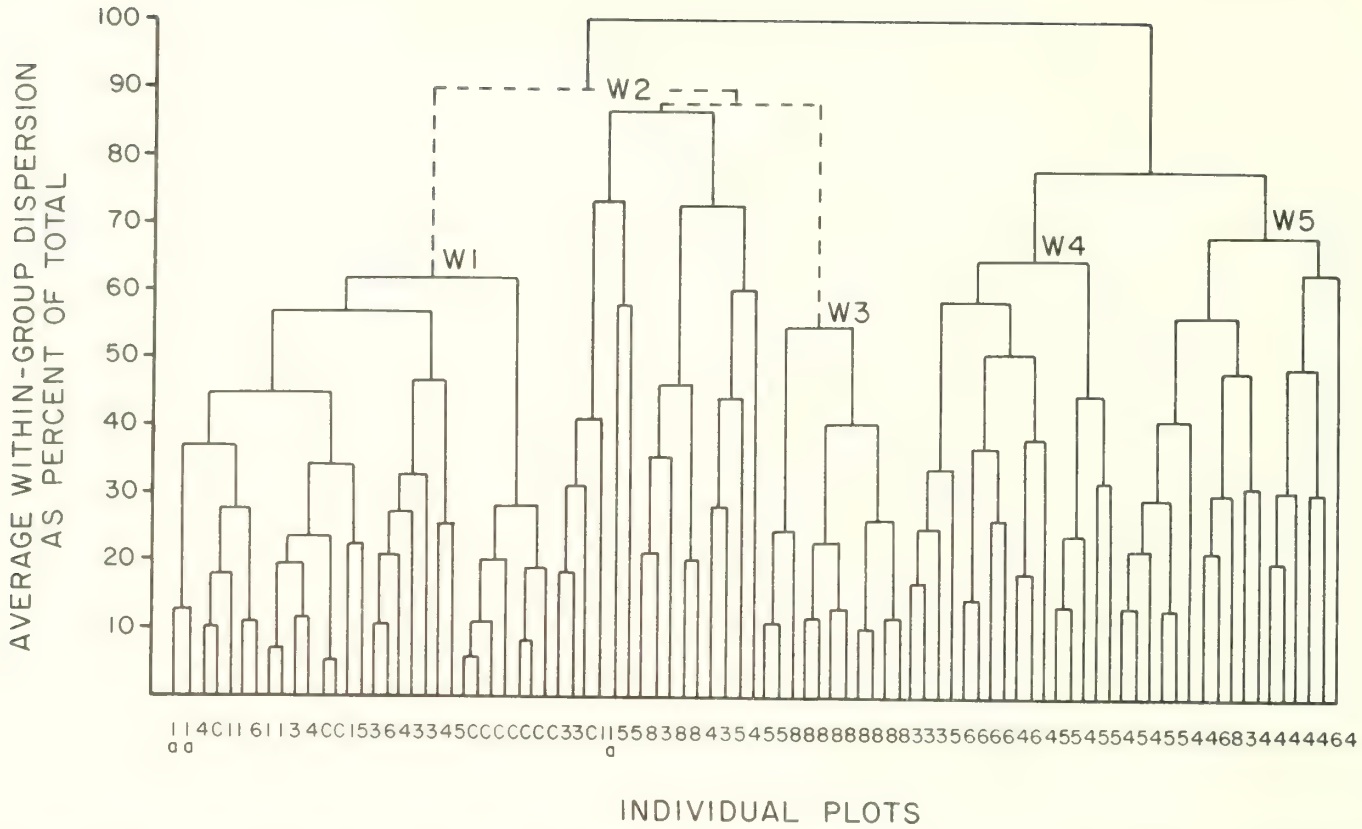

Figure 2.—*Grouping of plots from cluster analysis. Each plot is labled according to the block in which it is located. Five groups of plots are designated as W1 to W5. Dotted lines indicate a reversal, which is a geometric effect that results in a lowered average within-group dispersion when certain groups are joined in the hierarchy.*

4 tended to occur in W5 (table 4). Plots from blocks 1, 3, and 5 showed little association with any of the groups. Plots on Zimmerman soil dominated W1 whereas those on Sartell soil dominated W3, W4, and W5. The cluster groups were not significantly related to either elevation or slope. The same approach was used to evaluate which species were most strongly associated with which cluster groups (table 5).

Table 4.—*Relations of groups formed from cluster analysis (fig. 2) to fire (burning block), soil series, slope, and elevation. Relations were determined from contingency table analysis and subsequent examination of adjusted standardized residuals (Haberman 1973)*

	P	W1	W2	W3	W4	W5
Fire	0.000†	Control, 1[1]	8[2]	8	6	4
Soil series	.000†	Zimmerman	None	Sartell	Sartell[2]	Sartell[2]
Slope	.231	--	--	--	--	--
Elevation	.147	--	--	--	--	--

† Significant ($P \leq 0.05$).

[1]Where two category preferences were indicated by adjusted standardized residuals >2.00, they are listed here in order of preference.

[2]Only a weak preference was indicated for any category by an adjusted standardized residual >1.00 and <2.00.

Because cluster analysis forms distinct groups of plots, it was not possible to determine the relations of individual plots to one another outside the group structure. Consequently, reciprocal averaging (Hill 1973) was used to look at all plots simultaneously and see their relations to one another. The resultant ordination of plots is shown in figure 3. From the ordination, it is apparent that plots from certain blocks (e.g., the control block) tended to be quite similar with respect to species composition, but that there was a considerable amount of overlap.

Thus, both cluster analysis and reciprocal averaging indicated that there was a tendency for plots in certain blocks to have similar species composition, and that no block had such a unique species composition that it was completely distinct from all other blocks. The control plots were apparently more similar to one another than were the plots in any of the burned blocks.

Table 5.—*Characteristic species of each group of plots formed from cluster analysis (see fig. 2.), determined from contingency table analysis and subsequent examination of adjusted standardized residuals (Haberman 1973)*

Group				
W1	**W2**	**W3**	**W4**	**W5**
Amphicarpa bracteata	*Amphicarpa bracteata*	*Celastrus scandens*	*Andropogon gerardi*	*Ambrosia psilostachya*
Galium boreale	*Carex* spp.	*Comandra richardsiana*	*Andropogon scoparius*	*Asclepias* spp.
Parthenocissus vitacea	*Corylus americana*	*Coreopsis palmata*	(*Schizachyrium scoparium*)	*Calamovilfa longifolia*
Quercus ellipsoidalis-	*Rhus glabra*	*Cyperus* spp.	*Asclepias* spp.	*Helianthemum bicknellii*
overstory density,	*Rubus* spp.	*Parthenocissus vitacea*	*Cyperus* spp.	*Lespedeza capitata*
basal area		*Prunus* cf. *virginiana*	*Lathyrus venosus*	*Panicum oligosanthes*
		Quercus macrocarpa	*Rhus glabra*	*Panicum perlongum*
		Rhus radicans	*Smilacina stellata*	*Panicum* cf. *praecocius*
		Scutellaria parvula	*Sorghastrum nutans*	*Physalis virginiana*
		Quercus macrocarpa-	*Stipa spartea*	*Poa* spp.
		overstory density,	*Viola pedata*	*Rhus glabra*
		basal area		*Tradescantia occidentalis*

DISCUSSION

Although no distinct patterns in overall species composition could be found among the burned blocks, the majority of species in the understory, shrub, and overstory layers had significantly different distributions with respect to burned blocks versus the control block. However, the response of various groups of species was different. In the understory, 9 of the 12 grass species had significantly different average frequencies with respect to burning blocks. Although five grass species were found in the control plots, no grass species had its highest average frequencey in the control block. The sedges (*Carex* spp. and *Cyperus* spp.) were common throughout the study area, but *Carex* spp. had its highest average value in the control block whereas *Cyperus* spp. had its lowest average value in the control block. Forbs showed a similar pattern to grasses. Of the 25 forb species, 17 had significantly different distributions with respect to burning blocks; none of the 17 had its highest average values in the control block. Three of the 11 woody species in the understory layer had maximum values in the control block, whereas four had maximum values in the burned blocks; the four others showed no significant relationship to blocks. In summary, all grasses and forbs that showed a significant relationship to blocks had maximum average values in the burned blocks; approximately half the sedge and woody species also had maximum values in the burned blocks while the other half had maximum values in the control block.

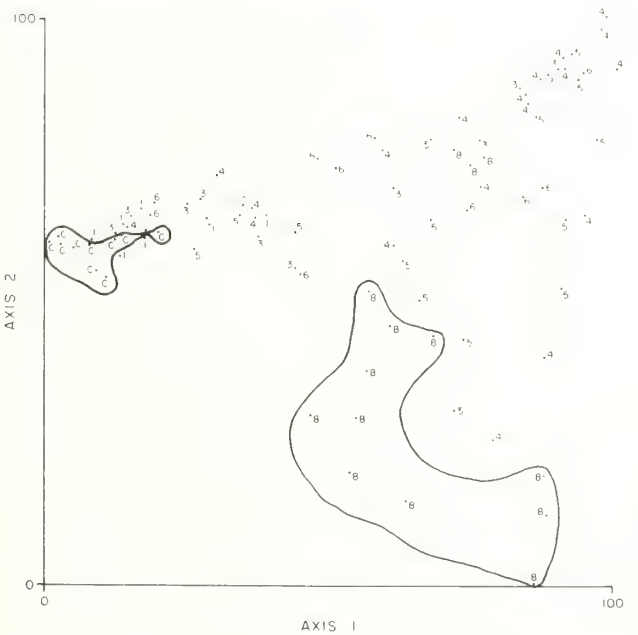

Figure 3.—*Distribution of plots on the first two axes from reciprocal averaging ordination. Each point is labeled according to the block in which it is located.*

Only three species (northern pin oak, bur oak, and American hazel) occurred frequently enough in the shrub layer to be analyzed. The most obvious result was that the shrub layer was virtually absent in the burned blocks (reaching a maximum of 4 percent cover in block 8) while reaching approximately 14 percent cover in the control block. In all blocks, American hazel was the single biggest contributor to shrub cover. Although American hazel was most prominent in the shrub layer of the control block, it is also able to maintain itself by sprouting following

fire, as evidenced by its occurrence in the understory plots of most burned blocks. This is consistent with other studies (Axelrod and Irving 1978, Buckman 1962), which have shown that although the average size of hazel stems may be reduced by low intensity burning, it is hard to eliminate hazel with such fires.

Northern pin oak was the most common overstory species in the study area. It had maximum average density (353 stems per acre) and basal area (113 square feet per acre) in the control block with minimum average density (40 stems per acre) in block 5 and minimum average basal area (26 square feet per acre) in block 8. Thus, even though blocks 5 and 8 have been burned periodically since 1965 and 1967 respectively (see table 1), the pin oak overstory has not been reduced to the 5 to 15 stems per acre levels of early oak savannas as reported by Bray (1955). Bur oak was not as abundant overall as pin oak, but it did occur in all blocks except 1 and 1a. In contrast to pin oak, bur oak had its maximum average density (136 stems per acre) and basal area (39 square feet per acre) in a burned block (8); in fact, block 8 was the only block in which bur oak was more abundant than pin oak in the overstory.

Differences in bur oak density and basal area among blocks were most likely related to preburn conditions because mature bur oak is quite fire resistant (Fowells 1965). The low-intensity prescribed burns resulted in little mortality to large diameter, thick-barked stems. Since small stems were rather rare, the fires probably had little influence on the advancement of such stems into the overstory.

Northern pin oak is less resistant to fire, possibly because of its thinner bark. In a specific comparison of block 3 and the 10 control plots immediately adjacent to block 3, White (1983) determined that pin oak density was 50 percent less in the annually burned block. These two areas were almost identical in environmental and preburn conditions (as determined from early air photos and average overstory age). Thus, it was assumed that the lower density in the burned block was due to considerable fire-caused mortality of small pin oak stems (White 1983). The current differences in density of pin oak among blocks is probably due in part to fire influence on smaller stems. Differences in preburn abundance of larger stems is also likely, since many of the burn blocks were not as similar to the unburned control as was block 3.

It is tempting to ascribe all the differences in individual species abundances among blocks to the influence of prescribed burning. However, this cannot be done for two reasons. First, it was not possible to statistically separate the effects of burning from the effects of soils because not all burning treatments were conducted on both soil series, as mentioned earlier. The influence of soil would appear to be relatively minor, however, because the two soil series are so similar in texture, pH, nutrient status, and water-holding capacity (see Grigal *et al.* (1974) for a more complete description of each series). A similar problem exists for differentiating the influences of fire and elevation. With only 10 species showing significant relationships to elevation, and with the range of elevation being small (≤22 feet), it is unlikely that elevational differences were of major importance.

Second, and more importantly, preburn stand structure and species composition were not known. Use of an unburned control block partially alleviated this problem, but it is not clear how well the control represented the pretreatment stands of each burned block. Although all the blocks were dominated by an oak canopy prior to burning, differences in structure and composition due to natural variation as well as occasional wood cutting, grazing, and burning most likely interacted with fire to produce the plant communities seen today.

Cluster analysis and reciprocal averaging were used in an attempt to discern differences among the blocks in terms of overall species composition. Although there was a tendency for certain blocks (e.g., control) to have similar composition among many of the plots in the block, no block had a distinctly unique species composition. This was not surprising given the relative uniformity of environmental conditions throughout the study area and the apparently individualistic (Gleason 1917, 1926) distribution of species with respect to blocks.

CONCLUSIONS

Several conclusions can be drawn from this study concerning the utility of prescribed burning for oak savanna restoration. First, fire has apparently altered the structure of the plant community. Grasses and forbs were more abundant in the burned blocks. Since many of these species are more common in prairies and savannas than in closed canopy forests (Curtis 1959), this effect was probably linked to the lower overstory densities and basal areas found in the burned blocks. Sedges and woody species in the understory had mixed responses to burning treatments. Species in the shrub layer were virtually absent in the burned blocks. Burning reduced the oak overstory, primarily by killing smaller diameter pin oak stems.

Second, it was not possible to distinguish among the prescribed burning regimes in terms of which was best suited for oak savanna restoration. In all the burned blocks, at least one species reached its maximum abundance; in five of the seven blocks, between four and eight species reached their maximum abundance. Although fire seemed to promote prairie and savanna species, different burning regimes could not be qualitatively separated. In other words, many different periodic burning schedules shifted the community towards oak savanna, but the development pattern differed in details.

Third, pretreatment community structure and composition probably influenced the effects of burning. Postfire structure and composition may best be predicted on a species-specific basis. By knowing what species are present on a site (or surrounding a site) prior to burning, and by knowing how each species responds to fire (e.g., by individual resistance, sprouting, germination of buried seeds or incoming seeds), one may predict the effects of fires of different characteristics (intensity, frequency, size, etc.). Relations between fire characteristics and the life history attributes of individual species are well-documented for some ecosystems (e.g., Keeley 1981, Noble 1981), but information is lacking on many species in many ecosystems.

Finally, although prescribed burning may promote savannalike conditions, it did not, even after 15 years, completely restore the CCNHA communities to presettlement conditions as described by Bray (1955). Part of the problem appears to be the resistance of large (≥10 in. d.b.h.) stems to relatively low intensity fires and to fires with low residence times. Such trees were typically killed only when localized fuels were heavy, usually due to the presence of broken tops, or downed trees.[8] Varying the frequency of burning should have resulted in different burn intensities because of differential fuel buildup between fires. However, since the burns at CCNHA were conducted in the spring when fuels and/or soils were still relatively moist, and since fuel buildup may not have been very great with a maximum of 3 years rest between burns (table 1), larger trees were seldom killed. More intense burns, burns conducted under higher ambient temperatures and when root reserves are low, or burns with longer residence times would probably kill more of the large trees,[8] but might also increase the risk of a fire escaping and increase the risk of severely damaging more understory species. If the management objective is to reduce the overstory quickly and promote typical savanna/prairie understory species, perhaps overstory reduction by cutting or girdling, followed by prescribed burning, would best meet the objective. If more modest overstory reduction and understory promotion is the objective, any one of the regimes tried at CCNHA should be effective. Safety should, of course, always be a primary concern, and patience is necessary as immediate restoration is not likely. Also, the uses of prescribed fire for restoration and maintenance should be considered separately. The type of fire (frequency, intensity, season, etc.) needed for restoration of the savanna community may be quite different from the type of fire needed to maintain the savanna community once it is achieved.

[8]*Frank D. Irving, Professor, University of Minnesota; personal communication.*

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Prescribed burning for oak savanna restoration in central Minnesota. Res. Pap. NC-266. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 12 p.

Low intensity, spring prescribed burns have been used since 1964 at the Cedar Creek Natural History Area in Minnesota in an attempt to restore the area to an oak savanna. Burned areas are now more savannalike (having greater grass and forb and lower shrub and tree representation) than unburned areas but still have higher overstory densities than apparently existed in presettlement times. No particular burning frequency could be distinguished as best for savanna restoration. Results indicated a possible interaction between fire effects and pretreatment stand structure and composition.

KEY WORDS: Fire ecology, fire effects, prescribed burning, oak, savanna.

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Adjusting STEMS Growth Model for Wisconsin Forests

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ADJUSTING STEMS GROWTH MODEL FOR WISCONSIN FORESTS

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Forest growth projection systems for estimating individual tree growth, developed from data collected over a large geographic region, furnish broad-scale regional estimates (Wykoff *et al.* 1982, USDA Forest Service 1979). These regional systems may not provide satisfactory subregional projections as demonstrated by Smith (1983) in Michigan; they do not directly account for macro-climatic variations and macro-soil differences. However, with appropriate adjustment, the benefits of the growth, mortality, and regeneration models established from large data sets can be retained for application on specific sites.

Various approaches have been proposed to adjust regional growth models for local use. Gertner (1984) applied a sequential Bayesian procedure to adjust the model's parameters. Stage (1981) proposed a logarithmic transformation to adjust basal area growth rate using past growth information. On the other hand, Smith (1983), used a more elementary ratio of the means adjustment by species for each of three size classes. This approach was used to adjust an earlier Lake States STEMS version (Hahn *et al.* 1979) for use in northern Michigan.

This paper presents a simple method for adjusting the tree diameter growth estimates of STEMS, the Stand and Tree Evaluation and Modeling System of the North Central Station (Belcher *et al.* 1982). We give coefficients for adjusting the Lake States STEMS to the forests of northern and central Wisconsin.

BACKGROUND

A comprehensive growth projection system, STEMS, has been developed for the Lake States (Belcher *et al.* 1982). This regional growth model has many strengths; some result from the size and breadth of the data base used. The STEMS data base included 1,501 plots containing multiple measurements on 92,649 trees. Data came from cutting experiments, demonstration woodlots, industrial continuous inventory systems, and personal records of forest growth from across the Lake States. These data included a wide range of forest types, varying species composition, sites, stand structures and densities for even- and uneven-aged stands (Christensen *et al.* 1979).

STEMS uses species-specific, individual-tree-based growth and mortality models formulated on principles of biological growth. The growth model treats the forest community as a cluster of interacting, dynamic trees. The processes involved were observed over a broad range of forest conditions. The large size of the data base permitted the development of complex interacting model forms. The flexibility of the resulting models facilitates their use in a variety of region-wide inventory and silvicultural analyses.

Special features and constraints are included in the model forms to produce biologically reasonable behavior for certain rarely encountered extremes. Hahn and Leary (1979) constrained tree diameter growth to be less than or equal to a biologically realistic potential growth. Silvicultural literature was consulted to determine reasonable upper d.b.h. limits for each species. Also, a maximum stand basal area limit was included in the competition modifier (Holdaway 1984) to restrict stand density to biologically realistic values.

In spite of the broad data base and biologically formulated models, applications and testing (Holdaway and Brand 1983) revealed small systematic errors for some species and conditions. There are several potential causes for this. The tree growth model coefficients were developed mainly from research plots. Such plots usually are chosen for their good location and minimum natural damage. They are usually carefully managed, resulting in a more uniform stand than would be found on general forest land. When these models are used to project stands that have not been maintained under the same optimal conditions growth is usually overpredicted (Bruce 1977).

Also, the available sources for the calibration data were mostly young established stands—approximately 90 percent of the trees were from 3 to 7 inches

for softwoods and 5 to 11 inches for hardwoods. Thus the growth models were extrapolated beyond the limits of the calibration data in order to accurately constrain growth estimates at the upper diameters. Extrapolation problems also existed at the lower limits of the calibration data for many of the species. Fourteen species had very few observations below 4 inches. As a result, the growth function was developed from data representing anywhere from 25 to 60 percent of the full range of diameter for each species—although the mid diameters were well represented.

A time element is also involved. The forest is a dynamic system undergoing continual change. The model development data is aging—most initial measurements were taken between 1945 and 1960, with final remeasurements made in 1975 and 1976. Has the general forest condition changed recently and if so, what factors are contributing to the change? The major factors possibly affecting the forest condition are changes in the macroclimate, insect and disease outbreaks, and forest decline due to acid deposition.

Climate is never static. Precipitation and temperature, which affect growth, fluctuate both yearly and also over longer time periods. The average annual northern hemispheric air temperature has been slowly dropping since 1940. This cooling followed a 60-year warming of the northern hemisphere. Climatic records of the past show that coolings last at least 40 years (Bryson 1974). Kalnicky (1974) indicated that the temperature across Wisconsin has followed the same cooling trends. These climatic fluctuations over decades have biological ramifications affecting the length of growing seasons, precipitation distribution, species distribution, tree growth, and pathogen activity (Layser 1980, Moran and Morgan 1976). Consequently, even modest temperature changes between the calibration period and future periods could have an effect on the accuracy of tree growth projections.

Three species in the Lake States—balsam fir, black spruce, and elm—have been subjected to insect or disease outbreaks. None of the damaging agents involved were present at high levels on the calibration locations during the measurement interval. Since then, these insect and disease infestations have spread into much of the area (Holdaway and Brand 1983), often reducing growth. To model current growth for these species, more recently collected data must be incorporated into the original model.

Forest decline due to acid deposition is a recent conjecture. The Lake States region has only moderate levels of acid deposition, increasing in magnitude along a gradient from northern Minnesota to southern Michigan. What would be the effect of such a condition on forest growth projections? Much of the calibration data for the STEMS model was collected during a period that was relatively unaffected by acid deposition, and thus the basic model coefficients would estimate a "normal" growth condition. However, in recent years, acid deposition has been increasing. If slight decreases in growth were occurring as a result of acid deposition, the "normal" STEMS model would be expected to overgrow trees on more recent validations.

Thus, problems originating from the use of experimental plots, possible long-term cooling of the climate, and/or possible forest decline due to acid deposition, would all result in overestimation of diameter growth on the general forest plots used in more recent studies. These results have been confirmed by the validation of STEMS (Holdaway and Brand 1983) where diameter growth was consistently overpredicted on all properties by an average of 0.11 inches in 10 years. Limitations in the original data base could result in underestimation or overestimation of diameter growth for certain diameter sizes. One route to achieving up-to-date resource information consists of adjusting the growth model to reflect the ongoing changes inherent in a dynamic system. This paper presents a simple method to adjust STEMS for these combined factors.

WISCONSIN APPLICATION

Wisconsin is partitioned into five geographically homogeneous survey units—the Northeast, Northwest, Central, Southeast, and Southwest Units (fig. 1). The Northern and Central Units—heavily glaciated leaving gravel hills, sandy plains, bare rock outcrops, extensive swamps and many lakes and streams—are largely forested. Roughly 70 percent of the two northern survey units and 39 percent of the Central Unit are in commercial[1] forest land (Spencer and Thorne 1972). This area is characterized by high annual precipitation, received predominantly during the summer and increasing as one moves northward (Rauscher 1984).

Remeasurement forest inventory plots from these three northern units were used to develop the methods described in this report. The two southern units were excluded since they are chiefly agricultural and were distinctly different from the north and central in climate. Subregional adjustments of regional growth models should be restricted to small regions of essentially uniform climate and similar broad physiographic features.

[1]*Commercial forest land is land capable of growing industrial wood and not reserved from timber harvesting.*

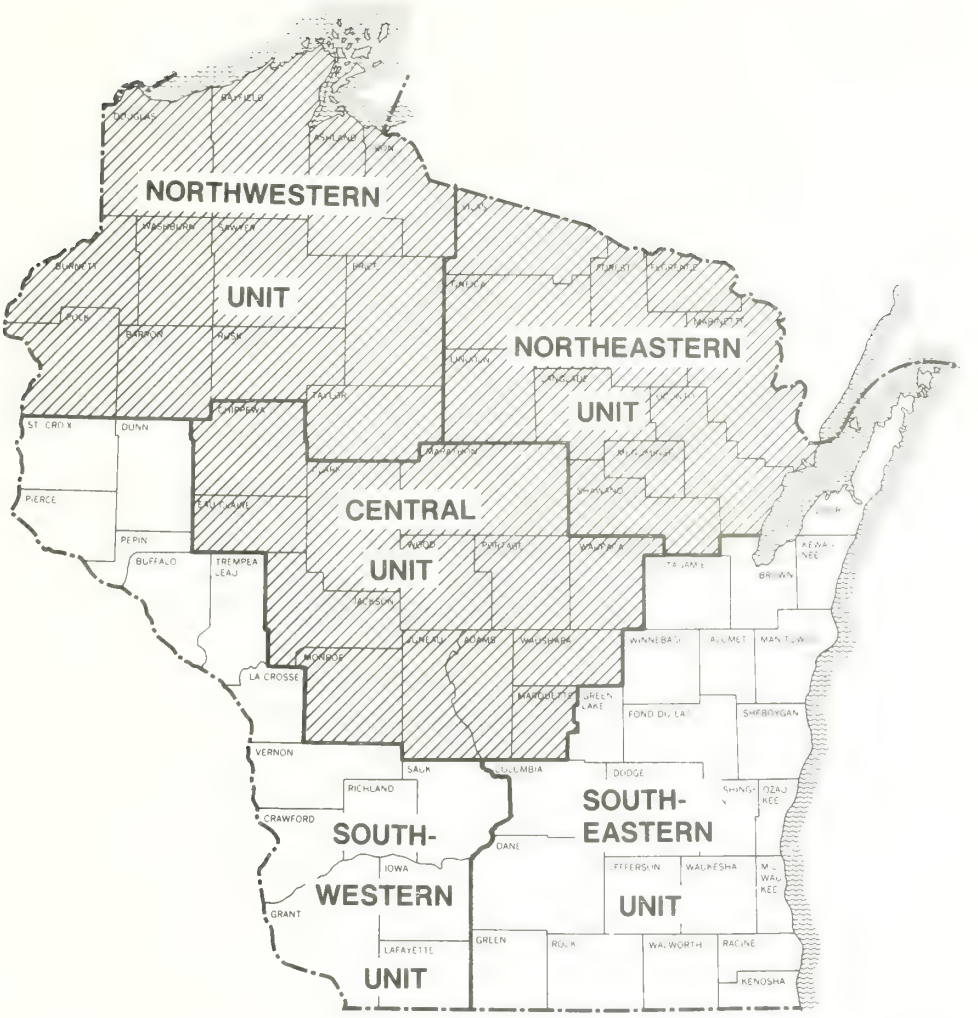

Figure 1.—*Location of Wisconsin Survey Units—data from the three shaded units were used to adjust the Wisconsin forests.*

METHODS

Data Base

Permanent plots from the 1966-1969 survey of non-National Forest land and the 1974-1976 survey of the Chequamegon and Nicolet National Forests were remeasured in 1983. The permanent plots, systematically distributed across each Unit, were variable-radius plots established at 10 points uniformly spaced over an acre. At each point, trees 5.0 inches d.b.h. and larger were sampled with a 37.5 factor prism. At the first three points tree saplings (d.b.h. 1.0 to 4.9 inches) were recorded for fixed area subplots. Only forest survey data for the Northeast, Northwest, and Central Survey Units, including the National Forests within these units, were used (fig. 1).

In 1968, forests in Wisconsin were generally young and rebuilding with the predominance of stands originating around 1920 (Spencer and Thorne 1972). Eighty-three percent of the stands were less than 70 years old. Despite the general youth of the forests, there were small areas of overmature stands within most forest types. Consequently, the data base contained ample moderate sized trees with fewer large trees. Trees under 5 inches were well represented because of the three fixed radius subplots taken on each plot. Approximately 90 percent of all trees were between 1 and 14 inches—a considerable increase in the d.b.h. range noted earlier for the calibration data base, especially for the softwoods.

Stand history obtained during the second measurement was used to identify all plots disturbed within the past 15 years. Disturbed plots, 32 percent of the original plots, were removed; 1,177 plots were retained for the analysis (table 1). Initially, every fourth plot was reserved for validation.

Table 1.—*Number of nondisturbed remeasured plots on commercial forest land in Wisconsin used in the analysis*

Survey Unit	Non-National Forest lands	National Forest lands	All
Northeast	308	113[1]	421
Northwest	407	88[2]	495
Central	261	0	261
All	976	201	1,177

[1]Nicolet National Forest.
[2]Chequamegon National Forest.

Analysis

STEMS[2] was used to grow the trees from the time of the earlier survey to 1983. Tree species, midpoint observed d.b.h.[3], and annual predicted and observed growth were used for developing the adjustment function. From this information, species-specific mean annual growth errors and ratios of predicted over observed growth, grouped by 2-inch diameter classes up to 30 inches, were graphed by d.b.h. class and survey unit. The graphs indicated distinct curvilinear error patterns related to tree d.b.h.

The merits of multiplicative and additive adjustment models were compared using a second-order polynomial equation. Each model was examined for long-term projections under a wide selection of stand characteristics. The additive model was more realistic in overall projections of stand characteristics. On the average, it accounted for 3 percent more variability than did the multiplicative model, using ratio-of-means estimates. In addition, the multiplicative model does not have the flexibility of the additive model to increase or alter growth for large diameter trees, a major disadvantage.

The additive diameter adjustment (ADJ) for the annual growth of a tree,

$$ADJ = a_1 \cdot DBH + a_2 \cdot DBH^2 + a_3 \ , \qquad (1)$$

yields a new d.b.h. estimate, $DBH_{NEW} = DBH + ADJ$. DBH and DBH^2 were retained in equation (1), i.e. a_1 and/or a_2 not zero, only if their contribution to the prediction was significant at the 0.05 level. A large, negative diameter adjustment, which could produce negative growth, is prevented by restricting growth after the adjustment to nonnegative values.

Preliminary results showed that the mean 10-year d.b.h. error was reduced from 0.17 inches before adjustment to 0.03 inches after adjustment on the validation plots. The final model coefficients were based on the 1,177 combined calibration-validation plots to strengthen coefficient estimation for species and diameter classes having few observations.

RESULTS

Coefficients for the diameter adjustment function were calculated for 25 species groups (table 2). The model showed close agreement between predicted and observed d.b.h.: maximum differences over various initial conditions were seldom greater than 0.10 inches in 10 years. With the growth adjustment, the average 10-year diameter prediction error based on 17,646 trees decreased from 0.16 inches to 0.02 inches; the standard deviation of the prediction error decreased, going from 0.70 inches to 0.65 inches.

Previous validation results for unadjusted STEMS (Holdaway and Brand 1983) on two National Forests in Wisconsin and two in Michigan, plus an experimental forest in Minnesota, revealed overprediction of growth for the middle diameter classes. The diameter adjustment corrected much of this problem (fig. 2).

A related area of concern, also revealed during the previous STEMS validation, was the overprediction of growth for overstory trees, i.e. trees with an initial relative d.b.h. (relative d.b.h. = d.b.h./average d.b.h.) greater than 1 (Holdaway and Brand 1983). The diameter adjustment reduces this overprediction by about 75 percent (fig. 3). The reduction of the average error and the damping of these two error patterns provide a general measure of confidence in the adjusted model.

Diameter (DBH) errors measure how well the growth component functions; number of trees (NT) errors how well the mortality component functions and its response to the growth function; and basal area (BA) errors, a combination of the two, measures

[2]*The mortality model used is the original model described in Buchman (1979).*

[3]*Using the midpoint d.b.h. removed the effect of varying interval lengths in the data.*

Table 2.—*Annual diameter adjustment function*[1] *coefficients for 25 species groups in North and Central Wisconsin*

Species group	Trees	Coefficients			Annual d.b.h. adjustment		
		a_1	a_2	a_3	1	10	20
	Number				*Inches*		
Jack pine	664	−0.0174	0.00065	0.069	0.052	−0.040	−0.019
Red pine	390	.0000	−.00017	.018	.018	.001	−.050
White pine	538	−.0043	.00011	.029	.025	.003	−.013
White spruce	227	−.0225	.00067	.050	.028	−.108	−.131
Balsam fir	771	−.0112	.00040	.030	.019	−.042	−.034
Black spruce	316	−.0248	.00162	.037	.014	−.049	−.049
Tamarack	342	−.0093	.00042	.048	.039	−.003	.030
N. white-cedar	813	−.0050	.00000	−.004	−.009	−.054	−.104
Hemlock	452	−.0043	.00022	.039	.035	.018	.041
Black ash	605	−.0115	.00032	.051	.040	−.032	−.051
Silver maple	48	.0109	.00000	−.106	−.095	.003	.112
Red maple	1,792	.0008	.00004	−.017	−.016	−.005	.015
Elm	344	−.0102	.00023	.028	.018	−.050	−.084
Yellow birch	453	−.0021	.00010	.001	−.001	−.010	−.001
Basswood	813	.0000	.00007	−.037	−.037	−.030	−.009
Sugar maple	2,251	.0014	.00002	−.024	−.023	−.008	.012
White ash	148	−.0113	.00066	−.002	−.013	−.048	.037
White oak	480	−.0079	.00039	.048	.040	.008	.046
Select red oak	1,158	.0015	−.00003	−.026	−.025	−.014	−.008
Other red oak	697	.0026	.00000	−.088	−.085	−.062	−.036
Bigtooth aspen	588	.0124	−.00022	−.079	−.067	.023	.080
Quaking aspen	2,168	−.0132	.00079	.031	.019	−.022	.084
Paper birch	1,242	−.0066	.00038	.011	.005	−.017	.032
Other hardwoods	219	.0085	−.00026	−.088	−.080	−.030	−.022
Noncommercial	175	−.0046	.00000	−.070	−.075	−.116	−.116
Total	17,694						

[1]General model is $ADJ = a_1 \cdot DBH + a_2 \cdot DBH^2 + a_3$. The adjustment is added to the annual diameter growth, such that growth ≥ 0.

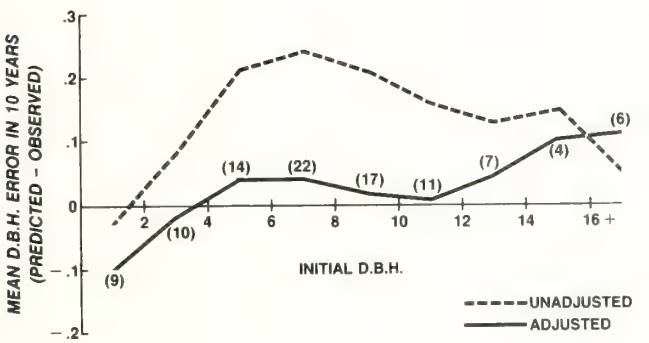

Figure 2.—*Mean 10-year d.b.h. errors plotted against initial d.b.h. for all trees. The percent of the observations in each class is given in parenthesis.*

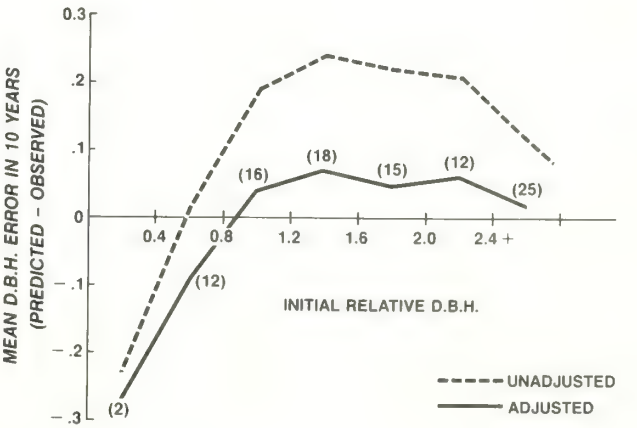

Figure 3.—*Mean 10-year d.b.h. errors plotted against initial relative d.b.h. for all trees. The percent of the observations in each class is given in parenthesis.*

how well the model functions as a whole. Thus, an evaluation of the DBH errors and NT errors separately, plus the BA errors, helps understand how the system is operating.

Error patterns and interactions for DBH errors after adjustment are shown for basal area by diameter classes (table 3). Although the overall DBH error is low, some potential problem areas are evident. The model appears to have a systematic bias with regard to basal area. It overpredicts for low basal area stands and underpredicts for high basal area stands. The worst overprediction is for the 3 percent of all trees that are found in the very low basal area plots. In the low basal area stands there appears to be a bias with respect to tree size, with overpredictions of DBH increasing with tree size.

Analysis of NT error patterns by basal area and average stand diameter classes (table 4) shows the number of small trees (trees <4 d.b.h.) is overestimated when stand basal area is less than 75 square feet and greatly underestimated for the more dense stands. There is a sharp decreasing trend in estimating NT for the youngest stands (average d.b.h. <4 inches). However, because very young stands have a large number of trees, mortality errors are magnified when expanded to a per acre basis. This trend is most marked for the young stands with higher basal area (75 square feet or more). These plots account for 19 percent of all plots in this study.

Finally, performance of the adjusted growth model in combination with the mortality model, as measured by the mean BA error (table 5), shows slight overestimation uniformly spread over the BA—DBH classes. The separate trends in DBH and NT were muted when the components were combined. Obviously, even large errors in the number of very small trees have very little influence on estimating stand basal area.

In summary, the major problem areas are:

1. The adjusted STEMS Model overgrows the larger trees (DBH ≥ 4 inches) on understocked plots (below 25 square feet/acre), representing one percent of the trees.
2. The model severely overestimates NT (or underestimates mortality) on very young stands (average d.b.h. <4 inches), especially for BA >75 square feet/acre. Translated into trees, this means that the system may be off by 60 to 80 trees on young stands composed of over 1,000 trees per acre. The conditions under which this kind of error occurs are found on 19 percent of the plots and, presumably, roughly 19 percent of the land area.

DISCUSSION AND CONCLUSIONS

The design of STEMS provides coverage for a wide variety of conditions encountered in the Lake States, and the coefficients of the model are based on data throughout the region. Evidence suggests that the performance of the model on a subregion of the Lake States could be improved by developing adjustment coefficients that more accurately reflect local growing conditions.

Table 3.—*Mean d.b.h. errors in 10 years by basal area and diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of trees appear in parenthesis. Positive values are overpredictions*

Stand basal area (ft^2/ac)	Tree diameter (inches at breast height)				
	0.0–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
	Inches				
0–24	0.11 (208)	0.24 (151)	0.25 (62)	0.56 (49)	0.22 (470)
25–74	−.08 (1,350)	.12 (1,996)	.21 (1,233)	.26 (636)	.11 (5,215)
75–124	−.07 (1,271)	.02 (2,936)	−.01 (2,383)	.08 (1,527)	.01 (8,117)
125+	−.06 (574)	−.06 (1,323)	−.16 (1,186)	−.10 (761)	−.10 (3,844)
All classes	−.06 (3,403)	.04 (6,406)	.01 (4,864)	.08 (2,973)	.02 (17,646)

Table 4.—*Mean number of trees error in 10 years by stand basal area and average diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of plots appears in parenthesis. Positive values are overpredictions*

Stand basal area (ft^2/ac)	Average stand diameter (inches as breast height)				
	0.–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
	Trees/acre				
0–24	17 (86)	2 (36)	−1 (6)	1 (8)	11 (136)
25–74	16 (301)	9 (184)	0 (21)	8 (4)	13 (510)
75–124	−40 (169)	2 (216)	−2 (17)	4 (4)	−15 (406)
125+	−93 (52)	0 (67)	−1 (5)	−3 (1)	−39 (125)
All classes	−9 (608)	4 (503)	−1 (49)	3 (17)	−3 (1,177)

I have demonstrated a simple method to recalibrate a regional tree growth model for use in a subregion of similar climate and geography—namely the commercial forests of northern and central Wisconsin.

Tree growth models for estimating the biological behavior of and constraints on tree growth are nonlinear and often very complex in how the various submodels interact. Even a simple change in how one aspect of the model functions can have complex

Table 5.—*Mean stand basal area error in 10 years by basal area and average diameter class for all Wisconsin data sources using the STEMS model with diameter adjustment. The number of plots appears in parenthesis. Positive values are overpredictions*

Stand basal area (ft^2/ac)	Average stand diameter (inches at breast height)				
	0.0–3.9	4.0–7.9	8.0–11.9	12.0+	All classes
	Sq ft/ac				
0–24	4 (86)	1 (36)	2 (6)	3 (8)	3 (136)
25–74	3 (301)	4 (184)	3 (21)	11 (4)	4 (510)
75–124	1 (169)	3 (216)	0 (17)	11 (4)	2 (406)
125+	−3 (52)	−1 (67)	−2 (5)	2 (1)	−2 (125)
All classes	2 (608)	3 (503)	1 (49)	7 (17)	2 (1,177)

effects elsewhere in the model. When changes are made, all aspects of the model performance must be evaluated. Since mortality is modeled as a function of d.b.h., mortality will also be "adjusted" due to the adjustment of d.b.h. in the growth model.

The analysis of the diameter adjustment revealed a few conditions where the adjusted model performed poorly, especially in underestimating mortality on young, well-stocked stands. Because of the small diameter of the trees involved, this problem does not affect the basal area error. The analysis shows the model adjustment will improve model performance for the vast majority of forest conditions.

Extrapolation of these adjustment functions very far beyond the limits of the available data may be unwise. Since only 2 percent of the trees in the calibration were above 20 inches, I recommend using the 20-inch adjustment for all trees above 20 inches. For black spruce and the noncommercial species, the adjustment becomes too large beyond the data range. For these two species the value at 10 inches should be used for all trees greater than 10 inches.

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Describes a simple procedure for adjusting growth in the STEMS regional tree growth model to compensate for subregional differences. Coefficients are reported to adjust Lake States STEMS to the forests of Northern and Central Wisconsin—an area of essentially uniform climate and similar broad physiographic features. Errors are presented for various combinations of stand and tree variables.

KEY WORDS: Lake States species, modeling, subregion, forest growth, projection system.

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Factors and Equations to Estimate Forest Biomass in the North Central Region

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Smith, W. Brad.
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Green weight of wood and bark can be greatly affected by moisture content. Average moisture content percentages and green weight conversion factors are presented for 42 tree species groups. Equations are also presented to compute average green weight of tops and limbs as well as stumps.

KEY WORDS: Green weight, moisture content, boles, limbs, stumps.

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FACTORS AND EQUATIONS TO ESTIMATE FOREST BIOMASS IN THE NORTH CENTRAL REGION

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As forest biomass estimates become more commonplace, there is an increasing need for organizations disseminating this information to specify the assumptions their estimates are based on. This is particularly critical in regions of the country where weight scaling of harvested wood is becoming popular and where woody biomass as an energy source is being promoted on a large scale.

The Forest Inventory and Analysis (FIA) research work unit at the North Central Forest Experiment Station has reviewed the literature and developed a set of factors for use in reporting biomass in its inventory reports. These factors and their use to estimate biomass of wood and bark of forest trees in the North Central region[1] are presented here.

Although specific gravity and oven-dry weights of wood and bark reported for a given species in the literature are relatively consistent, green weight data can be variable. Major discrepencies generally occur in the value used for moisture content of the wood or bark. Factors that further confound green weight data found in the literature include weather, time of year, location, and genetic variability of the species reported.

To provide consistent biomass statistics related to forest inventory and timber drain in our reports we have made some assumptions about the characteristics of green wood and bark based upon information found in the literature. The Wood Handbook published by the U.S. Forest Products Laboratory (1974) served as the primary source of information on specific gravity and moisture content ranges for the wood of most commercial species in the region. Other data from the literature were then used to enhance this information and fill in the gaps—particularly for detailed information about bark, which is essentially lacking in the handbook.

In developing biomass factors, it is important that the specific gravity used be based upon wood or bark that is as close as possible to the moisture content for which the factor is desired (Haygreen and Bowyer 1982). Using the specific gravity and moisture content data found in the literature (table 1), we derived the average green weight per cubic foot for wood and for bark in pounds by species group.

There is far less information in the literature on bark than wood for species in the North Central region. Thus, bark characteristics for many species were synthesized from available information. Based on data presented by Manwiller (1975), Warluft (1974), and Erickson (1972), we assumed bark to have the same average moisture content as that of the wood at any given location along the stem. Bark thickness data were pooled from several timber utilization studies described by Blyth and Smith (1980) that have been conducted by the North Central FIA unit over the past 20 years. These data were analyzed by Raile (1980) and average bark percent by species was estimated using the relation of diameter-inside-bark to diameter-outside-bark. Because the bark data collection and analysis process did not address bark fissures and voids, we adjusted data for several species to account for bark fissures based upon data presented by Cassens (1976) and Krier and River (1968).

The top and limbs may represent 5 to 40 percent of the total biomass of a tree. To estimate this biomass we developed regressions to predict the weight of wood and bark in the top and limbs (excluding foliage) above the bole (4-inch top diameter outside bark) as a function of the bole biomass for trees larger than 5 inches d.b.h. Regressions based upon

[1]*The North Central Forest Experiment Station FIA research work unit is responsible for forest resource evaluation in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, and Wisconsin.*

Table 1.--Specific gravity, green and dry weight, and moisture content for wood and bark of North Central species groups

Species group	Wood			Bark					
	Specific gravity[1]	Green weight (lbs/cu.ft.)	Oven dry weight[2] (lbs/cu.ft.)	Specific gravity[1]	Green weight (lbs/cu.ft.)	Oven dry weight[2] (lbs/cu.ft.)	Percent of bark[3]	Average percent moisture content[4]	Stump regression coefficient
Jack pine	0.40	47	25	0.34 (8,14,18,22,33)	40	21	17	90 (8,9,21)	0.007017
Red pine	.41	49	26	.24 (8,18)	29	15	16	90 (8,9)	.007176
White pine	.37 (9)[5]	43	23	.49 (22,30)	59	31	16	90 (36)	.008269
Ponderosa pine	.38	45	24	.34 (30)	40	21	15	90 (36)	.007176
Southern pine	.47	58	29	.32 (29,33)	40	20	15	100 (36)	.007176
Other pines	.40	45	25	.40	45	25	15	80 (36)	.007176
White spruce	.37	46	23	.29 (14,18,33)	36	18	10	100 (8,9)	.010699
Black spruce	.38	45	24	.38 (14,23,33)	46	24	14	90 (36)	.008877
Balsam fir	.34	46	21	.38 (8,14,18,33)	53	24	15	120 (8,9,21)	.009967
Hemlock	.38	50	24	.40 (23,33)	53	25	21	110 (9)	.008579
Tamarack	.49	55	31	.30 (23,33)	34	19	13	80 (3)	.008877
Baldcypress	.42	57	26	.40	55	25	13	120 (36)	.008269
Eastern redcedar	.44	43	27	.40	40	25	12	60 (36)	.008877
Northern white-cedar	.29	36	18	.30	38	19	12	100 (9)	.011946
Other softwoods	.38	43	24	.45	50	28	13	80 (36)	.008877
White oak	.60	59	37	.53 (7,22)	53	33	18	60 (5,20,26,38)	.009727
Red oak	.56	63	35	.65 (7,22)	74	41	14	80 (5,37,38)	.008908
True hickory	.64	64	40	.60 (26)	59	37	13	60 (5,26,38)	.008980
Pecan hickory	.60	59	37	.60 (26)	59	37	13	60 (5,26,38)	.008980
Basswood	.32	40	20	.45	56	28	16	100 (36,37)	.009639
Beech	.56	59	35	.56 (23,33)	60	35	7	70 (15,37,38)	.010202
Yellow birch	.55	61	34	.56	63	35	12	80 (15)	.009968
Hard maple	.56	63	35	.54 (7,18)	61	34	12	80 (7)	.008894
Soft maple	.49	55	31	.52	58	32	12	80 (5,26)	.008476
Elm	.46	58	29	.28 (22,23,33)	34	17	14	100 (15)	.010422
Black ash	.45	50	28	.45	50	28	14	80 (36)	.011016
White and green ash	.54	54	34	.34	34	21	16	60 (5,20)	.008728
Sycamore	.46	58	29	.45	56	28	8	100 (36)	.008980
Cottonwood	.37	50	23	.43 (22,30)	59	27	15	120 (36)	.011145
Willow	.34	46	21	.43	59	27	16	120 (36)	.011145
Hackberry	.49	52	31	.49	53	31	15	70 (19)	.010422
Balsam poplar	.37 (9)	50	23	.50 (9)	68	31	18	120 (8,9,21)	.006594
Aspen	.39 (2)	48	24	.50 (14,18,33)	62	31	18	100 (2,8,9)	.007369
Paper birch	.48	54	30	.51 (7,14,33)	58	32	16	80 (9,15)	.008380
Sweetgum	.46	60	29	.46 (26)	61	29	15	110 (5,20,26)	.008980
Black tupelo	.46	58	29	.46 (26)	58	29	15	100 (5,26,38)	.008980
Black cherry	.47	49	29	.48 (30)	51	30	10	70 (36)	.008980
Black walnut	.51	57	32	.28 (25)	31	17	15	80 (36)	.008980
Butternut	.36	44	22	.40	50	25	15	100 (36)	.008980
Yellow-poplar	.40	52	25	.40 (22,26)	53	25	15	110 (5,20,26,37,38)	.008980
Other hardwoods	.42	46	26	.42	47	26	15	80 (36)	.008980
Noncommercial species	.45	50	28	.45	50	28	15	80 (36)	.008980

[1] Based on weight oven-dry and volume when green.

[2] Computed from specific gravity presented (based on green volume).

[3] Expressed as percent of green wood volume. To express as percent of total green volume including bark, multiply decimal value of percent shown by (1.0 - (1.0/(1.0 + decimal value of percent shown))).

[4] Expressed as percent of oven-dry weight. To express as a percent of green weight, divide green weight minus dry weight by the green weight.

[5] Numbers in parentheses indicate literature source used to establish value estimate.

biomass data for whole trees presented by Myers *et al.* (1980), Steinhilb *et al.* (1984), and Carpenter (1983) were used to describe this relation. The basic data included foliage, so factors presented by Young *et al.* (1976) were used to deduct average foliage values before regression analysis. For all equations presented, d.b.h. is in inches, volume is in cubic feet, and biomass is in pounds.

The regression equations to estimate biomass in top and limbs (excluding foliage) for trees larger than 5 inches d.b.h. as a function of bole biomass (from a 1 foot stump to a 4-inch top diameter outside bark) by species group follow:

Pines and tamarack

$$\text{Total top biomass} = (0.092 + (1.0/\text{d.b.h.}^{1.628})) \times (\text{total bole biomass}) \quad (1)$$

Other softwoods

$$\text{Total top biomass} = (0.061 + (1.0/\text{d.b.h.}^{0.659})) \times (\text{total bole biomass}) \quad (2)$$

Aspen

$$\text{Total top biomass} = (0.106 + (1.0/\text{d.b.h.}^{0.832})) \times (\text{total bole biomass}) \quad (3)$$

Other hardwoods

$$\text{Total top biomass} = (1.0/\text{d.b.h.}^{0.471}) \times (\text{total bole biomass}) \quad (4)$$

The following regression equation is used to predict the average total above-ground biomass (excluding foliage) for all trees less than 5 inches d.b.h.:[2]

$$\text{Total biomass (pounds)} = 3.912 + \text{d.b.h.}^{2.4324} \quad (5)$$

Equations to determine bole volume of trees in the North Central region have been presented by Hahn (1975, 1976, 1984) and Smith and Weist (1982). Stump volume equations have been developed by Raile (1982) and shrub and herbaceous vegetation biomass equations are presented by Smith and Brand (1983). A simplified version of Raile's stump regressions is presented here for the wood volume of 1-foot stumps (excluding bark). Coefficients for the following equation are presented in the last column of table 1:

$$\text{Stumpwood volume} = b_0 \times \text{d.b.h.}^2 \quad (6)$$

where b_0 is the species specific regression coefficient.

To demonstrate the use of the information described here, the total above-ground cubic-foot volume and biomass (excluding foliage) of a 15-inch basswood tree on site index 60 forest land in Indiana is calculated as follows:

1. Using the volume equation and species specific coefficients from Smith and Weist (1982) for basswood and factors from table 1, the bole and bark volume and biomass from a 1-foot stump to a 4-inch top diameter outside bark for this tree are:

$$\begin{aligned}
\text{Bole wood volume} &= 16.882 \times \text{SI}^{.572} \times [1.0 - e^{-.0001\text{dbh}^{2.707}}] \\
&= 16.882 \times 60^{.572} \times [1.0 - e^{-.0001(15)^{2.707}}] \\
&= 24.85 \text{ cubic feet} \\
\text{Bole bark volume} &= (\text{bark percent}) \times (\text{bole volume}) \\
&= 0.16 \times 24.85 \\
&= 3.98 \text{ cubic feet} \\
\text{Total bole volume} &= 24.85 + 3.98 \\
&= 28.83 \text{ cubic feet} \\
\text{Bole wood biomass} &= (\text{bole wood volume}) \times \\
&\quad (\text{species wood height per cubic foot}) \\
&= 24.85 \times 40 \\
&= 994.00 \text{ pounds} \\
\text{Bole bark biomass} &= (\text{bole bark volume}) \times \\
&\quad (\text{species bark weight per cubic foot}) \\
&= 3.98 \times 56 \\
&= 222.88 \text{ pounds} \\
\text{Total bole biomass} &= 994.00 + 222.88 \\
&= 1216.88 \text{ pounds}
\end{aligned}$$

2. Using regression equation 4 presented above, the biomass and volume of the top are:

$$\begin{aligned}
\text{Top biomass} &= (1.0/\text{d.b.h.}^{0.471}) \times (\text{total bole biomass}) \\
&= (1.0/15^{0.471}) \times 1{,}216.88 \\
&= 339.87 \text{ pounds (green weight)}
\end{aligned}$$

If we assume bark to be the same proportion of the top as of the bole:

$$\begin{aligned}
\text{Total top volume} &= 339.87/(.84 \times 40 + .16 \times 56) \\
&= 7.99 \text{ cubic feet}
\end{aligned}$$

3. Using the simplified stump regression for 1-foot stumps shown in equation 6 above and coefficient from table 1 for basswood, the volume and biomass of the 1-foot stump is:

$$\begin{aligned}
\text{Stump wood volume} &= .009639 \times \text{d.b.h.}^2 \\
&= .009639 \times 15^2 \\
&= 2.17 \text{ cubic feet} \\
\text{Stump bark volume} &= (\text{bark percent}) \times (\text{stump volume}) \\
&= 0.16 \times 2.17 \\
&= 0.35 \text{ cubic feet} \\
\text{Total stump volume} &= 2.17 + 0.35 \\
&= 2.52 \text{ cubic feet} \\
\text{Stump wood biomass} &= (\text{stump wood volume}) \times \\
&\quad (\text{species wood weight per cubic foot}) \\
&= 2.17 \times 40 \\
&= 86.80 \text{ pounds (green weight)} \\
\text{Stump bark biomass} &= (\text{stump bark volume}) \times \\
&\quad (\text{species bark weight per cubic foot}) \\
&= 0.35 \times 56 \\
&= 19.60 \text{ pounds} \\
\text{Total stump biomass} &= 86.80 + 19.60 \\
&= 106.40 \text{ pounds (green weight)}
\end{aligned}$$

4. Total tree weight and volume (above-ground including bark) are:

$$\begin{aligned}
\text{Total above-ground green weight} &= \text{bole} + \text{top} + \text{stump} \\
&= 1{,}216.88 + 339.87 + 106.40 \\
&= 1{,}663.15 \text{ pounds (excluding foliage)} \\
\text{Total above-ground tree volume} &= 28.83 + 7.99 + 2.52 \\
&= 39.34 \text{ cubic feet}
\end{aligned}$$

[2] *Equation developed by Gerhard K. Raile (personal communication, 1982) using data from Young* et al *(1976).*

FIA reports provide basic information on the timber inventory and drain. Biomass estimates for standing inventory rely upon development of methods to convert volume of inventory to weight of green wood and bark. Drain data, on the other hand, are often derived by determining the volume of solid wood represented by a given weight of rough green wood delivered to a primary user. Both of these situations are consistently addressed by the factors and equations presented in this report. The weight-per-unit-of-volume factors were validated by comparison with data from weight scale studies such as those by Lothner *et al.* (1974), Hardy and Weiland (1964), Upper Great Lakes Timber Inc. (1973), and Bowyer (1983). Biomass reported by FIA is an estimate of the green weight of standing timber and shrubs in the average moisture content condition.

Information in table 2 should be of particular interest to individuals or companies using weight scaling to buy wood. These columns provide values for average total weight of wood and bark for both 100-inch and standard cords, and conversion factors for estimating cord equivalents from rough green tons of wood and bark. These figures assume an average of 79 cubic feet of solid wood per standard cord and 82.3 cubic feet of solid wood per 100-inch cord (all USDA Forest Service FIA reports use standard cords). Stacking and average diameter of material may affect these solid wood relations in actual practice. Large diameter wood may increase the number of solid cubic feet per cord while poor stacking and rough or crooked bolts can reduce it. Specific knowledge of solid wood contents, therefore, would allow the user to adjust the factors presented as necessary.

Table 2.--Green weight conversion factors and moisture content for wood with bark for North Central species groups

Species group	Green weight Wood and bark/ cu.ft. of wood	Weight of 100" cords (lbs/cord)	Number of 100" cords per ton	Weight of standard cords (lbs/cord)	Number of standard cords per ton
Jack pine	54	4,428	0.4517	4,266	0.4688
Red pine	54	4,428	.4517	4,266	.4688
White pine	53	4,346	.4602	4,187	.4777
Ponderosa pine	51	4,182	.4782	4,029	.4964
Southern pine	64 (6)[1/]	5,248	.3811	5,056	.3956
Other pines	52	4,264	.4690	4,108	.4869
White spruce	50 (15)	4,100	.4878	3,950	.5063
Black spruce	51 (15,19)	4,182	.4782	4,029	.4964
Balsam fir	54 (15,35)	4,428	.4517	4,266	.4688
Hemlock	61 (35)	5,002	.3998	4,819	.4150
Tamarack	59 (35)	4,838	.4134	4,661	.4291
Baldcypress	64 (6)	5,248	.3811	5,056	.3956
Eastern redcedar	48	3,936	.5081	3,792	.5274
Northern white-cedar	40 (9)	3,280	.6098	3,160	.6329
Other softwoods	49	4,018	.4978	3,871	.5167
White oak	68 (9)	5,576	.3587	5,372	.3723
Red oak	73 (5)	5,986	.3341	5,767	.3468
True hickory	71 (5)	5,822	.3435	5,609	.3566
Pecan hickory	66 (9)	5,412	.3695	5,214	.3836
Basswood	49	4,018	.4978	3,871	.5167
Beech	64 (9,15)	5,248	.3811	5,056	.3956
Yellow birch	68	5,576	.3587	5,372	.3723
Hard maple	70 (15)	5,740	.3484	5,530	.3617
Soft maple	62 (5,15,35)	5,084	.3934	4,898	.4083
Elm	63 (9,15)	5,166	.3871	4,977	.4018
Black ash	57 (9)	4,674	.4279	4,503	.4441
White and green ash	60 (5,15)	4,920	.4065	4,740	.4219
Sycamore	62	5,084	.3934	4,898	.4083
Cottonwood	59	4,838	.4134	4,661	.4291
Willow	56	4,592	.4355	4,424	.4521
Hackberry	60	4,920	.4065	4,740	.4219
Balsam poplar	62 (35)	5,084	.3934	4,898	.4083
Aspen	59 (19,35)	4,838	.4134	4,661	.4291
Paper birch	63 (15,35)	5,166	.3871	4,977	.4018
Sweetgum	69 (5)	5,658	.3535	5,451	.3669
Black tupelo	67 (5)	5,494	.3640	5,293	.3779
Black cherry	54 (9)	4,428	.4517	4,266	.4688
Black walnut	62 (9)	5,084	.3934	4,898	.4083
Butternut	52	4,264	.4690	4,108	.4869
Yellow-poplar	60 (5)	4,920	.4065	4,740	.4219
Other hardwoods	53	4,346	.4602	4,187	.4777
Noncommercial species	58	4,756	.4205	4,582	.4365

[1/] Numbers in parentheses indicate literature source used to establish value estimate.

Using the information described in this paper, consistent above-ground biomass and timber drain values for inventories in the North Central region can be computed from basic forest inventory data such as are stored in FIA data bases described by Hahn and Hansen (1985). Biomass may also be computed on an oven-dry weight basis by using oven-dry weights per cubic foot provided in table 1 for each species.

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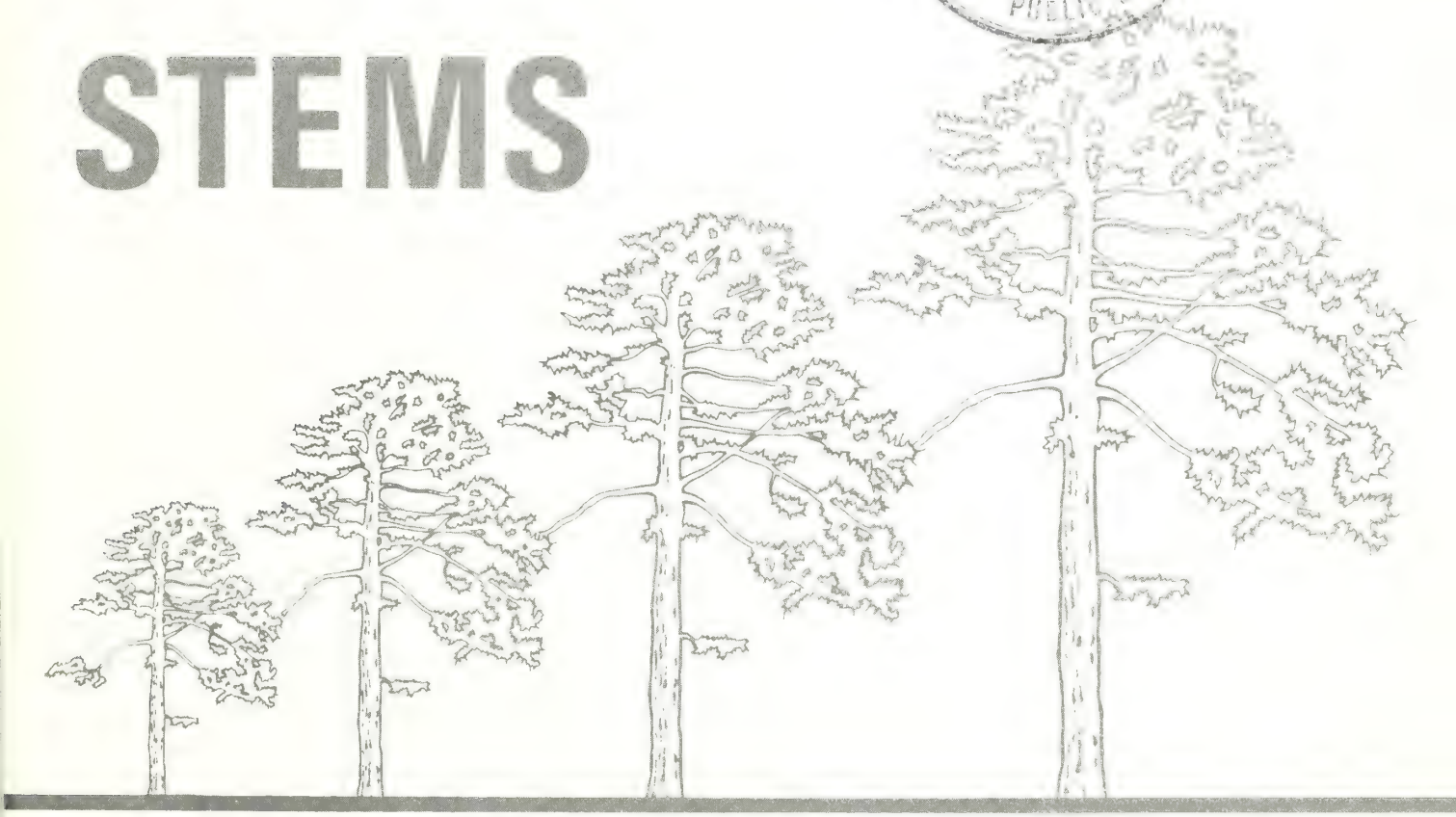
An Evaluation of Lake States STEMS 85

Margaret R. Holdaway and Gary J. Brand

NOV 21

STEMS



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An updated version of the Lake States variant of STEMS is evaluated and compared with the previous version. The new version is slightly more accurate and precise. The strengths and weaknesses of this tree growth projection system are also identified.

KEY WORDS: Validation, testing, growth model, prediction errors, model performance.

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AN EVALUATION OF LAKE STATES STEM S85

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In 1975, research was begun at the North Central Forest Experiment Station to develop a system to project tree growth in the Lake States region. This tree growth projection system (USDA Forest Service 1979) was later modified and renamed STEMS, Stand and Tree Evaluation and Modeling System (Belcher *et al.* 1982). In 1985 an updated version called STEMS85 was released.

A new model should replace a previous model only if judged better. When comparing alternative models, it is unlikely that one model will perform better for all stand conditions and forest types. The model chosen will depend on many aspects of model performance (the amount of bias and variability in the predictions, the relative importance of prediction errors, reasonable behavior when extrapolating to rare events) as well as nonperformance attributes (Buchman and Shifley 1983, Brand and Holdaway 1983).

STEMS' performance has been previously examined in detail (Holdaway and Brand 1983). The new version, STEMS85, is identical to STEMS in all but two aspects: (1) a diameter adjustment has been added to the growth component, and (2) the mortality model has been modified. The diameter adjustment[1] (Holdaway 1985) was added to correct diameter prediction errors. The mortality model in STEMS85 is a variation of the STEMS mortality model that includes an adaptation to more realistically predict survival rates for small trees and large, slow-growing trees (Buchman *et al.* 1983, Buchman 1983). Consequently, the new mortality function, although producing similar midrange results, has greater ability to forecast biologically reasonable behavior for trees at these two extremes.

This paper (1) compares the performance of STEMS85 with STEMS, (2) analyzes the performance of the STEMS85 tree growth projection system for a wide range of forest types, species, stand densities, and site qualities, and (3) identifies the strengths and weaknesses of STEMS85. Whenever possible, comparisons are made to the previous STEMS model. We evaluate the accuracy and precision of predictions of three key variables—d.b.h. (DBH), number of trees per acre (NT), and stand basal area (BA). DBH evaluates primarily the growth component of the model, NT evaluates primarily the mortality component, and BA evaluates the combination of these two components[2]. The results are presented in a simple format that can be interpreted without specialized statistical knowledge.

PROCEDURES

Data Base

The validation data base, not used in model development, consisted of remeasured inventory plots from the five locations listed below:

1. Cloquet Experimental Forest, Minnesota (Data courtesy of Alan Ek, College of Forestry, University of Minnesota)
2. Chequamegon National Forest, Wisconsin
3. Nicolet National Forest, Wisconsin
4. Hiawatha National Forest, Michigan
5. Manistee National Forest, Michigan.

The Cloquet plots were all 1/7 acre each with tree diameters greater than 4.9 inches recorded. The National Forest plots were 10-point clusters of variable radius plots (37.5 factor prism) for trees greater than 4.9 inches in diameter and a 0.01 acre sample for trees 1.0 to 4.9 inches in diameter. Nearly 12,700 trees were measured. The average initial stand age

[1] *STEMS85 does not use the white spruce diameter growth adjustment coefficients described in Holdaway (1985). Additional testing revealed that the white spruce adjustment coefficients produced inaccurate growth estimates.*

[2] *The growth and mortality components are intimately related—changing one changes the other. DBH errors are influenced by the accuracy of the mortality component. Likewise, NT errors are influenced by the accuracy of the growth component.*

was 46 years, with a maximum of 196 years; the average initial diameter was 8.2 inches; and the average time between measurements was 13 years.

Plot data included site index, stand age, measurement dates, and a list of trees. Data for each tree in the list included species code, tree factor (number of trees per acre represented by the measured tree), crown ratio code, and diameter and status code (alive, dead, or cut) for each measurement.

Basic Projection Data

The basic analysis involved calculating the error (i.e., predicted minus observed value) for each variable (DBH, NT, and BA). In general, the longer the prediction interval, the less accurate the prediction will be (Goodall 1972). Consequently, if the time intervals used vary greatly, it may be difficult to make any justifiable conclusions. To avoid these problems, we standardized the errors to 10 years using the equation:

$$10 \times \frac{(\text{Predicted attribute} - \text{observed attribute})}{\text{Number of years in measurement interval}} .$$

With this equation, overprediction errors are positive values and underprediction errors are negative values.

TEST RESULTS AND DISCUSSION

Overview

The STEMS85 model consistently predicted slower growth than the STEMS model on all five areas which was generally an improvement (table 1). The STEMS85 model gave more accurate mortality predictions, as measured by NT errors, on 3 of the 5 locations. BA estimates were better on three of the locations and worse on one. For all locations combined, there was an overall improvement in diameter growth estimation of 0.05 inches in 10 years (0.05 inches closer to zero) and in basal area estimation of 2.6 square feet in 10 years, but a slightly worse estimation of mortality. As measured by the standard deviation, STEMS85 is slightly more precise than STEMS for all three key variables—DBH, NT, and BA.

The slight underestimation of diameter growth has an advantage. Purely random error in the estimation of diameter induces a small but systematic error in the derived value of nonlinear functions (Mandel 1964) such as tree basal area. When expanded to a per-acre basis, these biases may cause observable overestimation of stand basal area. Comparing DBH and BA errors from this and the previous evaluation (Holdaway and Brand 1983) confirms this—on the average, an underestimation of DBH of 0.08 inches in 10 years produces zero error in basal area estimation, whereas an overestimation of DBH of 0.08 inches produces an overestimation of basal area of about 2 square feet in 10 years. Thus, a slight underestimation of diameter is preferable to a similar overprediction when accurate estimation of both diameter and basal area is important.

The following detailed analysis of various aspects of STEMS85's performance, with occasional comparison to STEMS, will instill both confidence and caution in its application.

DBH Errors (Growth Component)

For all areas combined there are no species with a mean DBH error greater than ±0.30 inches in 10 years when using STEMS85 (table 2), as contrasted with 5 species with the STEMS model. Mean DBH errors in 10 years for 4 of the 5 problem species have been greatly improved with the STEMS85 model:

Errors in DBH estimates for the 5 species with the worst STEMS performance

Species	STEMS	STEMS85
	Inches per 10 years	
White spruce	0.32	0.19
Northern white-cedar	.37	−.05
Basswood	.38	.11
White ash	.35	−.04
Northern pin oak	.76	.14

Five of the first 6 conifers (table 2) have some of the largest negative errors. Many of these trees came from the Cloquet Experimental Forest in northern Minnesota, where the largest underestimation of growth is found. Black spruce is the only species with consistently low values on all areas. Diameter growth for all species combined shows a small but consistent underprediction on 4 of the 5 areas. Diameter growth on the Manistee National Forest in lower Michigan is overestimated.

NT Errors (Mortality Component)

Information on the mortality component is provided by the NT errors (table 3). Overestimating the number of live trees on a stand indicates that the mortality function is not "killing" enough trees (mortality underestimated). Because predicted mortality is sensitive to predicted diameter growth, small errors in diameter growth estimates can result in noticeable errors in mortality estimates.

The four National Forests have variable radius plots with small trees (1 to 5 inches) measured on a

Table 1.--Summary of the mean and standard deviation of the errors in 10 years for STEMS and STEMS85 (The errors are evaluated for tree d.b.h. (DBH), number of trees per acre (NT), and stand basal area per acre (BA). Errors are computed as predicted attribute minus observed attribute.)

	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85	STEMS	STEMS85
Mean												
DBH (inches)	0.11	-0.06	0.06	-0.12	0.13	-0.03	0.09	-0.09	0.09	-0.06	0.28	0.15
NT (trees/acre)	2	6	6	0	-16	21	-18	1	5	1	2	12
BA (sq.ft./acre)	3.5	.9	4.2	-1.1	4.7	2.3	.8	-.8	2.2	-1.1	5.0	7.1
Standard deviation												
DBH (inches)	.63	.60	.54	.53	.63	.60	.69	.65	.67	.64	.69	.63
NT (trees/acre)	78	65	20	20	108	85	104	73	100	100	66	60
BA (sq.ft./acre)	13.4	12.1	9.4	9.8	13.3	11.9	12.4	11.5	14.2	12.9	19.0	14.1
Number of plots	822	822	292	292	123	123	145	145	114	114	148	148
Number of trees	11,182	12,696	4,572	5,267	1,587	1,753	1,775	1,992	1,720	1,897	1,528	1,787

Table 2.--Mean d.b.h. errors (inches) by Lake States species in 10 years using the STEMS85 model (The number of trees appears in parentheses. Positive values are overpredictions.)

Species	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	-0.11	(1,813)	-0.19	(1,334)	-0.12	(66)	-0.18	(52)	0.16	(182)	0.17	(179)
Red pine	-.16	(1,374)	-.18	(879)	-.28	(64)	-.13	(69)	-.34	(135)	.08	(227)
White pine	-.04	(310)	-.20	(139)	.05	(36)	-.16	(36)	.09	(74)	.52	(25)
White spruce	.19	(171)	-.11	(64)	1.16	(14)	.37	(54)	.09	(39)	-	
Balsam fir	-.19	(693)	-.25	(326)	-.17	(150)	-.09	(125)	-.15	(89)	.15	(3)
Black spruce	-.29	(769)	-.29	(614)	-.26	(29)	-.19	(42)	-.36	(82)	-.19	(2)
Tamarack	.07	(334)	.12	(278)	-.17	(27)	-.27	(21)	-.05	(7)	.78	(1)
N. white-cedar	-.05	(916)	-.12	(333)	-.03	(107)	-.01	(191)	-.02	(232)	.16	(53)
Hemlock	.11	(306)	-		.27	(50)	-.05	(122)	.19	(119)	.25	(15)
Black ash	.02	(189)	-.03	(51)	.16	(51)	.00	(35)	.03	(8)	-.09	(44)
Red maple	-.12	(798)	-.24	(68)	-.03	(191)	-.09	(64)	-.18	(258)	-.09	(217)
Elm	-.22	(194)	-		-.16	(48)	-.33	(126)	.08	(8)	.52	(12)
Yellow birch	-.09	(270)	.71	(2)	-.08	(92)	-.03	(78)	-.17	(83)	-.08	(15)
Basswood	.11	(274)	-		.01	(86)	.07	(150)	-.22	(5)	.62	(33)
Sugar maple	.01	(878)	-		.08	(293)	-.09	(354)	-.05	(164)	.34	(67)
White ash	-.04	(61)	-		-.19	(18)	-.43	(12)	-		.20	(31)
White oak	.21	(255)	-		-		-		-		.21	(255)
N. red oak	.01	(258)	-.51	(3)	.08	(119)	-.19	(25)	-.23	(24)	.06	(87)
N. pin oak	.14	(286)	-		.40	(4)	-		-		.13	(282)
Bigtooth aspen	.10	(227)	.45	(36)	-.11	(64)	-.14	(30)	-.05	(37)	.32	(60)
Quaking aspen	.08	(933)	.10	(388)	-.15	(134)	.04	(237)	.23	(118)	.25	(56)
Paper birch	-.03	(1,102)	.02	(752)	-.19	(101)	-.32	(123)	.05	(96)	.01	(30)
All[1]	-.06	(12,696)	-.12	(5,267)	-.03	(1,753)	-.08	(1,992)	-.06	(1,897)	.15	(1,787)

[1]Includes all species on the property

Table 3.--Mean number of trees errors (trees/acre) by Lake States species in 10 years using the STEMS85 model (The number of plots appears in parentheses. Positive values are overpredictions.)

Forest type	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	7	(127)	-4	(79)	16	(7)	42	(6)	42	(20)	-2	(15)
Red pine	4	(85)	-1	(49)	22	(6)	-6	(4)	-11	(11)	26	(15)
White pine	-1	(13)	19	(6)	-6	(2)	-41	(2)	-12	(3)	-	
White spruce	-13	(10)	5	(4)	-		-27	(4)	-45	(1)	-	
Balsam fir	30	(51)	13	(23)	32	(14)	7	(8)	124	(6)	-	
Black spruce	-16	(40)	-19	(29)	- 25	(2)	27	(3)	-22	(6)	-	
Tamarack	-11	(23)	-3	(19)	- 46	(4)	-54	(2)	-		-	
N. White-cedar	-10	(47)	11	(14)	-4	(2)	-25	(9)	-36	(14)	68	(2)
Hemlock	-24	(7)	-		-		-14	(4)	-38	(3)	-	
Lowland hardwoods	35	(30)	13	(3)	80	(5)	48	(2)	-43	(1)	29	(19)
N. hardwoods	13	(135)	-		31	(40)	10	(49)	-16	(28)	27	(18)
White oak	21	(15)	-		-		-		-		21	(15)
N. red oak	7	(15)	-		5	(4)	-109	(1)	-62	(2)	40	(8)
Oak-pine	-19	(10)	-		-		-		-39	(1)	-17	(9)
Oak-hickory	-9	(35)	-		- 82	(1)	-		-		-7	(34)
Aspen	5	(121)	11	(30)	14	(23)	-2	(42)	1	(14)	3	(12)
Paper birch	5	(58)	3	(36)	16	(8)	-10	(9)	45	(4)	-3	(1)
All	6	(822)	0	(292)	21	(123)	1	(145)	1	(114)	12	(148)

Table 4.--Mean basal area errors (sq.ft./acre) by Lake States species in 10 years using the STEMS85 model (The number of plots appears in parentheses. Positive values are overpredictions.)

Forest type	All		Cloquet		Chequamegon		Nicolet		Hiawatha		Manistee	
Jack pine	-2.5	(127)	-5.9	(79)	1.5	(7)	2.6	(6)	4.0	(20)	2.1	(15)
Red pine	-2.5	(85)	-3.6	(49)	2.8	(6)	-4.7	(4)	-9.1	(11)	4.2	(15)
White pine	-2.4	(13)	3.9	(6)	-2.7	(2)	-14.3	(2)	-6.6	(3)	-	
White spruce	-3.1	(10)	5.9	(4)	-2.4	(1)	3.6	(4)	-4.4	(1)	-	
Balsam fir	5.3	(51)	5.9	(23)	1.1	(14)	2.9	(8)	16.6	(6)	-	
Black spruce	-4.3	(40)	-6.4	(29)	-2.5	(2)	11.3	(3)	-2.9	(6)	-	
Tamarack	.0	(23)	1.7	(19)	-6.6	(2)	-10.2	(2)	-		-	
N. White-cedar	-.7	(47)	1.7	(14)	.6	(8)	-4.0	(9)	-4.8	(14)	19.9	(20)
Hemlock	-12.5	(7)	-		-		-11.8	(4)	-13.4	(3)	-	
Lowland hdwds.	16.4	(30)	4.4	(3)	18.2	(5)	3.1	(2)	-11.7	(1)	20.7	(19)
N. hardwoods	1.6	(135)	-		2.8	(40)	-1.2	(49)	-3.1	(28)	14.0	(18)
White oak	3.3	(15)	-		-		-		-		3.3	(15)
N. red oak	.6	(15)	-		-.7	(4)	-8.8	(1)	-8.7	(2)	4.7	(8)
Oak-pine	1.4	(10)	-		-		-		-21.3	(1)	3.9	(9)
Oak-hickory	.7	(35)	-		6.8	(1)	-		-		.5	(34)
Aspen	4.0	(121)	7.0	(30)	2.0	(23)	1.4	(42)	3.1	(14)	10.8	(12)
Paper birch	.7	(58)	1.0	(36)	1.1	(8)	-5.4	(9)	9.3	(4)	7.8	(1)
All	.9	(822)	-1.1	(292)	2.3	(123)	-.8	(145)	-1.1	(114)	7.1	(148)

0.01-acre fixed radius plot. Each tree measured on this fixed radius plot represents 100 trees per acre. If one of these small trees dies, the observed number of live trees per acre decreases by 100. This is the main reason why the errors were so much larger for these four locations than they were for either the calibration data or Cloquet. If the mortality function is accurate, these deviations should average out over all areas.

With STEMS85, only one forest type, lowland hardwoods, is in error by more than 30 trees in 10 years, as compared to five forest types with the STEMS model. The serious problem with some of the oak species in STEMS has apparently been corrected in STEMS85. Eight of the individual tracts were in error by more than 50 trees per acre with STEMS85, compared with 16 with STEMS.

BA Error (Overall Model)

The BA errors provide information on the combined growth and mortality predictions. For all the tracts, STEMS had four forest types with BA errors greater than ±9 square feet per acre in 10 years. With STEMS85, only two, hemlock (−12.5) and lowland hardwoods (16.4), have large BA errors (table 4).

Error Patterns

Errors in the three key variables—DBH, NT, and BA—graphed over various initial conditions help to highlight conditions where large errors occur (figs. 1 and 2). For example, large DBH errors occurred in STEMS when the initial basal area was low (third graph from the top in fig. 1). Many of the large errors occur where there are few observations. Errors in these classes are of concern only when projections are to be made for stands under these conditions. Because so much more variability exists in classes with few observations, caution needs to be exercised when emphasizing these trends.

Diameter error patterns for the two models are similar, but errors with STEMS85 were generally smaller. The STEMS85 overall reduction in predicted growth improves the error patterns, especially in terms of initial DBH and relative DBH. (Relative DBH for a tree is the ratio of its diameter to the average tree diameter for the stand.)

The STEMS model showed a marked overgrowth of overstory trees (as measured by relative DBH). The trend was bothersome because even a small overgrowth will be magnified with long projections. This problem has been corrected with STEMS85.

No strong trends emerge from the error patterns for the mortality component (fig. 2a). However, NT

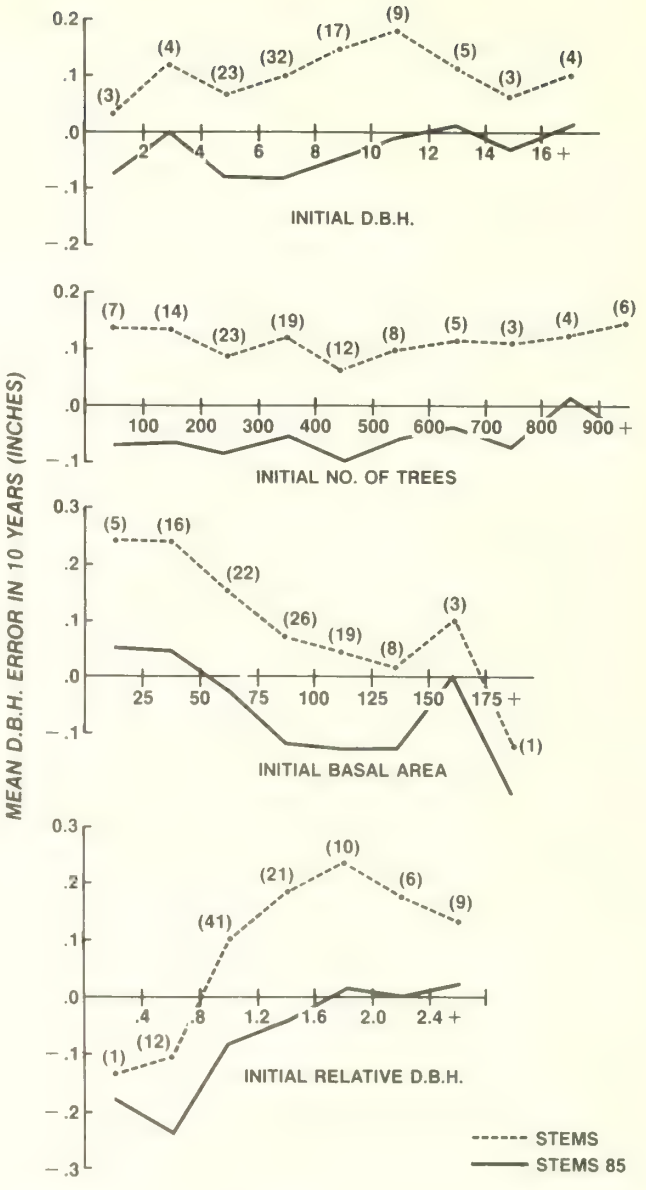

Figure 1.—*The mean DBH error in 10 years plotted against selected initial tree and stand conditions for STEMS and STEMS85. The percent of the observations in each class for both models is given in parentheses.*

variability increased for stands with low average DBH and many trees per acre. Both results are logical in that a greater number of trees will magnify NT errors. Also, NT was sharply underpredicted at high initial basal areas (1 percent of the observations).

Finally, the mean BA error (fig. 2b), a measure of overall model performance, decreases slightly as the initial basal area increases. Several examples investigated by Holdaway and Brand (1983) showed that a 10 percent error in DBH produces roughly a 20 percent error in BA, whereas a 10 percent error in

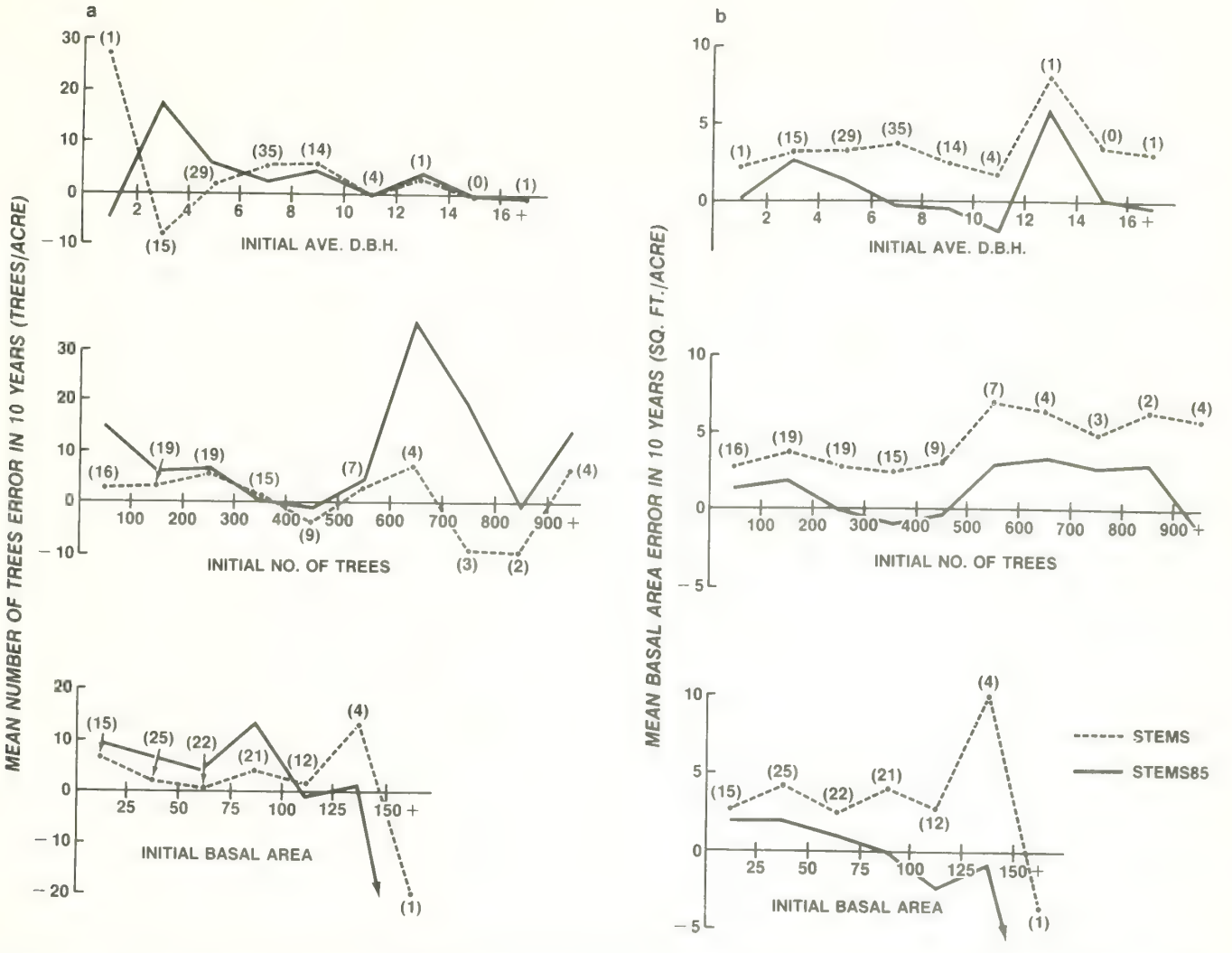

Figure 2.—*The (a) mean number of trees errors and (b) the mean basal area errors in 10 years plotted against selected initial stand conditions for STEMS and STEMS85. The percent of the plots in each class for both models is given in parenthesis.*

NT produced only a 10 percent error in BA. Thus, with these data, accuracy in predicting diameter growth is twice as important as accuracy in predicting mortality. In evaluating the data, the BA trend evident in the growth component is still present in the overall model.

DBH Error By Diameter Class

The growth component can be further analyzed by evaluating diameter errors for initial diameter classes (table 5). For all species combined, the STEMS85 model underestimated growth of trees between 4 and 8 inches; but for 8 inches and larger it reduced a problem with overprediction in STEMS.

The number of entries with a mean DBH error greater than ±0.30 inches in 10 years was reduced from 60 using STEMS to 27 using STEMS85. White spruce overpredictions with STEMS have been slightly improved. All other problem species with STEMS (northern white-cedar, basswood, northern pin oak, and bigtooth aspen) have been greatly improved with STEMS85 as measured by the errors in the DBH classes. No other species show large errors.

Species Mortality Rates

Mortality can be evaluated as a tree attribute in addition to evaluation as a stand attribute. We calculated the observed and predicted annual mortality rates for each species based on the number of trees that survive through an observation interval and the length of that interval (table 6).

The results for the two models show roughly the same overall accuracy and distribution of the errors (predicted - observed mortality rates) by species. Estimates for balsam fir and elm, which can be affected by insect or disease outbreaks, have now been improved in STEMS85. Although the problem with elm

Table 5.-- Mean d.b.h. errors (inches) in 10 years by species and diameter class for all validation data sources

Species	No. of trees[1]	Diameter class (inches) 0-3+	4-5+	6-7+	8-9+	10-11+	12-13+	14-15+	16+	All classes	Mean d.b.h. growth in 10 years
Jack pine	1,813	-0.04	-0.07	-0.13	-0.11	-0.12	-0.14	-0.24	-0.71	-0.11	0.97
Red pine	1,374	-.21	.01	-.12	-.42	-.48	-.28	-.20	-.02	-.16	1.72
White pine	310	-.73	-.31	-.37	-.14	.19	.48	.00	.07	-.04	1.82
White spruce	171	.40	-.02	.03	.37	.45	.43	.45	.34	.19	1.84
Balsam fir	693	.03	-.21	-.23	-.17	-.27	-.24	-.24	-	-.19	1.03
Black spruce	769	-.13	-.29	-.31	-.29	-.04	-	-2.20	-	-.29	.63
Tamarack	334	.24	.08	.04	.03	.34	.00	.65	-	.07	.68
N. white-cedar	916	-.09	-.12	-.07	.02	.06	.14	-.13	-.31	-.05	.76
Hemlock	306	.17	.00	.16	.07	.23	-.07	.10	.18	.11	.91
Black ash	189	-.08	-.03	.01	.07	.23	.05	-.22	-.18	.02	.66
Red maple	798	.13	-.15	-.17	-.11	-.19	-.17	-.45	-.08	-.12	1.20
Elm	194	-.18	-.17	-.26	-.03	-.23	-.58	-.01	-.43	-.22	1.32
Yellow birch	270	-.06	-.02	-.08	-.30	.09	.03	-.20	-.06	-.09	.92
Basswood	274	-.13	.37	.12	.03	.00	.05	.11	.33	.11	1.23
Sugar maple	878	.03	-.04	-.04	.01	.17	.08	.11	-.09	.01	1.13
White oak	255	.14	.24	.17	.24	.17	.19	.16	.43	.21	.89
N. red oak	258	-.05	.15	.02	-.08	.00	-.25	-.17	.25	.01	1.35
N. pin oak	286	-.36	-.03	-.15	.18	.28	.34	.41	.14	.14	1.12
Bigtooth aspen	227	-.06	.21	.19	.14	.02	-.23	-.29	-.15	.10	1.58
Quaking aspen	933	-.22	-.03	.16	.15	.13	-.03	.02	-.18	.08	1.41
Paper birch	1,102	-.20	-.12	-.05	.06	.05	.30	.27	-.15	-.03	1.16
All[2]	12,696	-.03	-.08	-.08	-.05	-.01	.01	-.03	.01	-.06	1.15
Percent trees in diameter class		7	23	32	17	9	5	3	4	100	

[1]Species with fewer than 100 observations have been omitted

[2]Includes species with fewer than 100 observations

has been lessened, the same general trends are evident. The predicted and observed elm mortality rates are close for all sources except the Manistee National Forest in lower Michigan. There, the observed mortality rate was 13 percent as compared to a predicted rate of just over 2 percent. As shown in Holdaway and Brand (1983), this is likely due to Dutch elm disease spreading into lower Michigan before entering Wisconsin and upper Michigan.

Precision

The DBH errors for STEMS85 are less skewed than for STEMS (fig. 3). There is little difference between the two models for the distribution of NT errors in 10 years, except that the distribution was slightly more peaked.

The graph of the distribution of BA errors in 10 years is similar in shape to that shown in figure 3, and so has not been presented. Again, the basal area errors are less skewed.

For 10 year projections with STEMS85, 75 percent of the trees had predicted diameters within 0.5 inches of the true value, 92 percent of the plots had predicted NT within 100 trees per acre, and

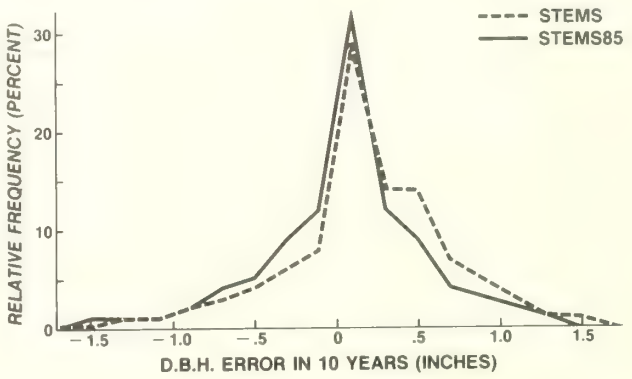

Figure 3.—*A comparison of the frequency distributions of the 10-year errors for STEMS and STEMS85 in predicting tree DBH for all validation sources.*

Table 6.--Predicted and observed annual tree mortality rates by Lake States species for all validation properties using STEMS85

Species	No. of trees	Annual tree mortality rate	
		Predicted	Observed
		Percent	
Jack pine	2,336	1.6	1.8
Red pine	1,397	.1	.3
White pine	363	.1	1.7
White spruce	187	1.0	.6
Balsam fir	1,092	1.1	2.0
Black spruce	1,024	2.7	1.4
Tamarack	370	1.3	.7
N. white-cedar	987	.4	.8
Hemlock	323	.5	.6
Black ash	254	1.5	2.0
Red maple	852	1.8	1.4
Elm	293	3.0	4.1
Yellow birch	321	1.1	2.0
Basswood	303	2.0	1.2
Sugar maple	946	1.3	1.7
White ash	65	1.7	2.2
White oak	274	.1	1.9
N. red oak	273	4.2	1.5
N. pin oak	312	5.1	2.6
Bigtooth aspen	270	2.3	1.6
Quaking aspen	1,468	1.9	3.3
Paper birch	1,191	.4	.9
All[1]	15,240	1.4	1.6

[1] Includes all species on the property

72 percent of the plots had BA values predicted to within 10 square feet. All three values are 4 percent higher than for STEMS.

Long-term Projections

Projections become less accurate as the projection interval increases. The original prediction system was calibrated with remeasurement data spanning 10 to 30 years. Thus, we feel that caution should be exercised in applying this growth projection beyond 30 years. Although constraints were built into the model that prevent grossly unrealistic behavior, the model may exceed or fall short of reasonable basal areas per acre on long-term projections. We recommend that long-term projections be compared critically with expectations based on professional judgment.

SUMMARY

We evaluated two growth models—the STEMS model and the current STEMS85 model—and found the two models to be fairly similar. However, the STEMS85 model was slightly more accurate and precise.

The important findings and observations from the tests on STEMS85, including the major areas of weakness, are:

1. On the five tracts studied the STEMS85 model undergrows trees on the average by 0.06 inches in 10 years. On 75 percent of these trees, it predicted the diameter to within 0.5 inches of the observed diameter after 10 years growth. Likewise, the model overestimated stand basal area on the average by 0.9 square feet per acre after 10 years growth; on 72 percent of these plots, it predicted the basal area to within 10 square feet per acre of the true value.
2. STEMS85 had far fewer species or forest types showing large errors for all three key variables. The major problem areas involved predicting mortality and stand basal area for lowland hardwoods.
3. In an evaluation of the error patterns for the two models, the STEMS85 model predicted slower DBH growth, which was generally an improvement. The main exception was extreme understory trees, representing 13 percent of the trees.
4. Tree diameter errors given by species and initial diameter classes show that the problem of overpredicting growth for trees larger than 8 inches has been corrected, but growth for trees from 4 to 8 inches is slightly underpredicted with STEMS85. Again, the number of DBH classes for each species with large positive or negative errors has been halved.

5. The problem of underpredicting mortality on balsam fir and elm has been improved with STEMS85.
6. STEMS85 predicts slower diameter growth for most trees, resulting in a slight underestimation of growth. Because of the positive bias in estimating stand basal area, this underestimation of growth is preferable to an equivalent overprediction.
7. Throughout the evaluation the number of and magnitude of the large prediction errors using STEMS85 were consistently reduced by 50 to 80 percent. The extent of this improvement is somewhat surprising, considering the slight increase in precision, along with the decrease in skewedness demonstrated in the precision analysis. Evidently, the model is sensitive to even slight improvements in precision.
8. Although the STEMS85 mortality predictions were not much improved, that model is known to have desirable biological characteristics that ensure reasonable estimates for large trees (Buchman *et al*. 1983).

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Research Paper **NC-270**

Wolf Population in the Central Superior National Forest, 1967-1985

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Mech, L. David.
Wolf population in the central Superior National Forest, 1967-1985. Res. Pap. NC-270. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 6 p.

Aerial radio-tracking and observation showed total number of wolves per year in 2,060-km^2 area varied from 35 to 87 in winter and from 30 to 78 in spring and generally declined because of a decreasing deer herd. Since winter 1977-1978, the population has remained relatively stable because an increasing proportion of it has switched to preying on moose. The number of wolves preying on deer has continued to decline.

KEY WORDS: Deer, moose, territoriality, home range, radio-tracking, telemetry, predator, prey, Minnesota.

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WOLF POPULATION IN THE CENTRAL SUPERIOR NATIONAL FOREST, 1967-1985

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Large carnivores are long-lived. Wolves (*Canis lupus*), for example, can live some 16 years in captivity (Young 1944) and at least 13 years in the wild (Mech 1981). Thus a complete understanding of their ecology and population dynamics requires long-term investigations. The longest study of wolf numbers has been conducted in Isle Royale National Park, Lake Superior, where wolves have been censused annually since 1959 (Mech 1966, Jordan *et al.* 1967, Peterson 1977, Peterson *et al.* 1984). That study has yielded several new insights into wolf and prey relationships (Allen 1979, Peterson *et al.* 1984). However, Isle Royale is a 544-km^2 island with the wolves living on a moose (*Alces alces*) economy. Thus it is useful to study wolf numbers in a larger, mainland ecosystem with a more complex prey base.

In 1966 such an investigation was begun in the central Superior National Forest of northeastern Minnesota. This area had the added advantage of background data from other studies (Olson 1938, Stenlund 1955). Earlier results of the present study have been reported (Mech 1973, 1977), but the present document summarizes the data from 1967 through 1985.

STUDY AREA

The present study area encompasses some 2,060 km^2 immediately east of Ely in the east-central Superior National Forest (48°N, 92°W). Although somewhat smaller than the areas reported on earlier, this study area encompasses the core of that region in which I have been able to monitor the wolf population during the entire 19-year period (fig. 1). The area represents approximately 3 percent of the total wolf range in Minnesota.

The topography varies from large stretches of swamps to rocky ridges, with altitudes ranging from 325 to 700 meters above sea level. Winter temperatures lower than −35°C are not unusual, and snow depths (usually from about mid-November through about mid-April) generally range from 50 to 75 cm on the level. Summer temperatures rarely exceed +35°C. Conifers predominate in the forest overstory, with the following species present: jack pine (*Pinus banksiana* Lamb.), white pine (*P. strobus* L.), red pine (*P. resinosa*), black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss), balsam fir (*Abies balsamea* (L.) Mill.), white cedar (*Thuja occidentalis* L.), and tamarack (*Larix laricina* (DuRoi) K. Koch). However, as a result of extensive cutting and fires much of the conifer cover is interspersed with large stands of white birch (*Betula papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx.). Detailed descriptions of the forest vegetation were presented by Ohmann and Ream (1969).

In the northeastern half of this study area, as well as in the region immediately north and east of it, the

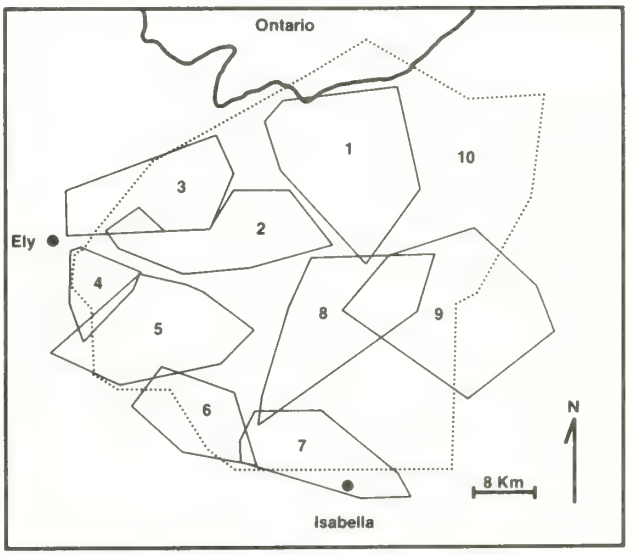

Figure 1.—*Wolf census area (2060 km^2 in the central Superior National Forest of northeastern Minnesota. Outlined, numbered areas represent minimum wolf pack territory boundaries for winter 1984-1985 as follow: 1, Ensign L. Pack; 2, Pagami Pack No. 2; 3, Wood L. Pack; 4, Birch L. Pack; 5, Little Gabbro Pack; 6, Jackpine Pack No. 4; 7, Sawbill Pack; 8, Quadga L. Pack No. 2; 9. Maniwaki L. Pack No. 2; 10, Malberg L. Pack (approximate territory because pack was not radioed in 1984-85).*

overwintering population of white-tailed deer (*Odocoileus virginianus*) were depleted about 1975 by a combination of a series of severe winters, maturing vegetation, and high wolf numbers (Mech and Karns 1977). Moose inhabit the entire study area but occur at a higher density in the northeastern half (Peek *et al*. 1976). In spring, some 32 percent of the deer inhabiting the southwestern half of the study area migrate into the northeastern half or beyond and return in fall (Hoskinson and Mech 1976, Nelson and Mech 1981, 1986). Beaver (*Castor canadensis*) are available throughout the study area, but generally only from about April through November because of ice during the rest of the year. Although all three prey species are consumed by wolves in the region (Frenzel 1974), since about 1975 the primary prey of wolves inhabiting the northeastern half has been moose, whereas those in the southwestern half have consumed primarily deer (Mech, unpublished).

Year-around hunting and trapping of wolves was legal until October 1970 when they were fully protected on federal land within the Superior National Forest by the U.S. Forest Service. In August 1974, wolves were protected by the Endangered Species Act of 1973. In 1978, the wolf in Minnesota was reclassified from endangered to threatened but remains legally protected except when taken by U.S. Fish & Wildlife Service agents reacting to depredations on livestock outside the present study area. However, in parts of the study area adjacent to towns (fig. 1), moderate illegal taking continues, primarily in fall and winter (Mech 1977, and unpublished).

METHODS

The primary technique used in this investigation has been live-trapping wolves, outfitting each with a radio-collar, aerially radio-tracking them at least once per week from April through November and at least twice per week from December through March, and aerially observing and counting them as often as possible, primarily from December through April (Mech 1974). The maximum number of wolves seen in each pack during December through February is considered the winter pack size, and the maximum seen in each pack in March and April represents the spring pack size (Mech 1973).

Pack territories based on radio locations were delineated for each radioed pack in the study area each year. The existence of nonradioed packs in the study area in any year were inferred from voids in the maps of the territorial mosaic. Incidental observations of nonradioed packs in these voids were used to represent sizes of these nonradioed packs. If such data were unavailable in a given year, pack-size estimates were made subjectively based on previous and later year's data for radioed packs occupying those territories. Data from before 1968 were based solely on observations of nonradioed packs during intensive aerial observation of the area.

In this estimate of wolf population trend, the number of lone wolves was considered inconsequential because their proportion of the population was low. During the earlier part of the present study, lone wolves were estimated at 7-14 percent of the population (Mech 1973), and loners comprised 16 percent of 282 wolves captured in and around the present study area (Mech unpublished).

Some data pertaining to individual pack years in the present article may differ from data presented previously (Mech 1973, 1977) because of reinterpretation of the data based on additional experience with these packs. Furthermore the wolf population trend may also vary slightly from previous publications because of the difference in the precise boundaries of the study areas considered. Nevertheless, the earlier results remain basically the same in the present study.

RESULTS

Some 250 wolves representing up to 13 packs in this study area were radio-tagged and studied from 1968 through 1985 (table 1). The number of radioed packs in the study area each winter and spring ranged from 1 to 8. Each radioed wolf was located an average of approximately 38 times per year, and they and their pack members were observed an average of approximately 18 times per year. Pack sizes varied from 2 to 15 during winter and from 2 to 11 during spring. Some packs disappeared as determined by the individual histories of radioed members of those packs (Mech unpublished). Sometimes their places were taken by new colonizing packs which may or may not have settled in precisely the same territories. A pack occupying a general area inhabited earlier by a radioed pack was usually listed under the same name (table 1) even though continuity via overlapping radio tenures was not always documented.

Generally the wolf population increased each year up to 86 percent from spring to winter as a result of reproduction, although during two summers wolf numbers actually decreased (table 2). From winter to spring the population decreased as much as 40 percent per winter as a result of mortality (Mech 1977) and dispersal (Mech in press).

The total number of wolves in the census area in winter varied from 35 to 87 and in spring, from 30 to 78 over the 19-year period, and generally declined (fig. 2). However, about 1978 wolves began recoloniz-

Table 1.—*Number of wolves in each pack in the east-central Superior National Forest study area*

	Packs																												Totals			
	Birch Lake		Ensign Lake		Little Gabbro		Greenstone Lake		Harris Lake		Jackpine		Manitwaki		Malberg Lake		Pagami Lake		Quadga Lake		Sawbill		Sumpet Lake		Thomas Lake		Wood Lake		Entire study area		On deer economy only	
Winter	W	S[1]	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S	W	S
1966-1967	(6)[2]	6	7	–	0	0	(4)	–	(5)	–	(6)	–	8	8	0	0	6	–	(6)	–	(4)	–	(9)	–	(5)	–	5	–	71	–	71	–
1968	(6)	–	(11)	–	0	0	(4)	–	(5)	–	(6)	–	6	–	0	0	(6)	–	(6)	–	(4)	–	(9)	–	5	–	(6)	–	74	–	74	–
1969	(6)	–	(11)	–	0	0	4	–	5[3]	5	(6)	–	10	7	0	0	(6)	–	(6)	–	6	–	(10)	–	6	–	6	–	82	–	82	–
1970	(6)	–	(11)	–	0	0	(4)	–	(7)	4	6	5	14	(7)	0	0	(6)	–	(6)	–	(4)	–	(10)	–	(6)	–	(6)	–	87	–	87	–
1971	(6)	(6)	(11)	11	2	2	5	5	9	6	7	6	7	(7)	0	0	6	6	6	6	3	2	(10)	(10)	(6)	6	(6)	5	84	78	84	78
1972	(6)	(5)	15	9	0	0	4	3	3	2	9	6	9	7	0	0	5	3	5	4	5	3	(10)	(9)	5	5	(6)	(4)	82	60	82	60
1973	6	(6)	10	5	0	0	6	3	4	4	7	6	9	3	0	0	0	0	2	2	4	(4)	(9)	(6)	7	0	(6)	3	70	42	70	42
1974	6	(6)	8	4	0	0	6	(4)	4	2	10	3	8	(6)	0	0	0	0	3	3	6	5	8	6	0	0	6	(3)	65	42	65	42
1975	(6)	(6)	3	2	0	0	7	5	2	2	1	1	9	9	0	0	0	0	6	5	3	3	(5)	3	0	0	2	2	44	38	44	38
1976	(6)	(6)	2	2	0	0	3	(2)	5	5	1	1	13	11	0	0	0	0	6	5	9	7	2	1	0	0	9	8	56	48	56	48
1977	6	5	4	2	0	0	0	0	5	3	(1)	(1)	9	(7)	0	0	0	0	4	4	6	5	0	0	0	0	8	6	45	33	45	33
1978	4	3	(8)	2	2	2	0	0	5	4	(1)	(1)	(9)	(7)	2	3	0	0	7	6	9	6	0	0	0	0	3	3	50	37	48	34
1979	3	2	(8)	(6)	5	(3)	0	0	2	2	(1)	(1)	(9)	(7)	(7)	(7)	0	0	0	0	(7)	(5)	0	0	0	0	4	(3)	46	35	39	29
1980	2	2	12	11	7	3	0	0	2	2	2	2	(9)	(7)	(7)	(6)	0	0	0	0	(7)	(5)	0	0	0	0	(6)	(6)	54	44	47	38
1981	3	3	(7)	(7)	2	2	0	0	2	2	5	2	9	(7)	(7)	(6)	0	0	0	0	5	4	0	0	0	0	8	8	48	41	41	35
1982	2	2	2	(2)	2	2	0	0	2	2	2	2	8	(7)	11	11	0	0	3	(3)	(6)	(5)	0	0	0	0	9	8	47	44	36	33
1983	2	2	6	(4)	5	(4)	0	0	2	2	(4)	2	3	1	12	11	0	0	(3)	3	6	(3)	0	0	0	0	7	5	50	37	38	26
1984	2	2	3	(2)	4	4	0	0	(2)	(2)	2	2	(0)	(0)	12	10	0	0	3	2	5	4	0	0	0	0	2	2	35	30	23	20
1985	5	4	7	(6)	5	4	0	0	0	0	4	3	6	7	(6)	(5)	6	3	5	3	(5)	(4)	0	0	0	0	5	(4)	54	43	30	22

[1]W = winter; S = spring.

[2]Numbers in parenthesis are subjective estimates.

[3]Underlined numbers indicate radio-tagged packs. Other figures are based on observations or tracks of non-radioed packs.

Table 2.—*Wolf population changes in the central Superior National Forest, based on data from table 1*

Year	Percent change in total numbers in study area				Percent change in wolf numbers on deer economy in study area			
	Winter to spring	Spring to next winter	Winter to winter	Spring to spring	Winter to spring	Spring to next winter	Winter to winter	Spring to spring
1967-1968	–	–	+4	–	–	–	+4	–
1969	–	–	+11	–	–	–	+11	–
1970	–	–	+6	–	–	–	+6	–
1971[1]	-7	+5	-3	–	-7	+5	-3	–
1972	-27	+17	-2	-23	-27	+17	-2	-23
1973	-40	+55	-15	-30	-40	+55	-15	-30
1974	-35	+5	-7	00	-35	+5	-7	00
1975	-14	+47	-32	-10	-14	+47	-32	-10
1976	-14	-6	+27	+26	-14	-6	+27	+26
1977	-27	+52	-20	-31	-27	+45	-20	-31
1978	-26	+24	+11	+12	-29	+15	+7	+3
1979	-24	+54	-8	-5	-26	+62	-19	-15
1980	-19	+9	+17	+26	-19	+8	+21	+31
1981	-15	+15	-11	-7	-15	+3	-13	-8
1982	-6	+14	-2	+7	-8	+15	-12	-6
1983	-26	-5	+6	-16	-32	-12	+6	-21
1984	-14	+80	-30	-19	-13	+50	-39	-23
1985	-20	–	+54	+43	-27	–	+30	+10

[1]Insufficient data available before this time because packs were not radioed.

ing the northeastern part of the study area in which overwintering deer and deer-killing wolves were then absent (Mech and Karns 1977). The newly colonizing Malberg L. Pack increased to 12 members by 1983, preyed exclusively on moose during winter, and occupied some 20 percent of the study area.

In spring 1984, four members of the Malberg L. Pack, including radioed 2-year-old wolf 6417, apparently split from the remainder of the pack and colonized the southeastern half of the previous winter's territory, expanded southeastward, and increased to seven; this pack was renamed "Maniwaki L. Pack" because it occupied the territory of the former Maniwaki L. Pack which had died out the previous year.

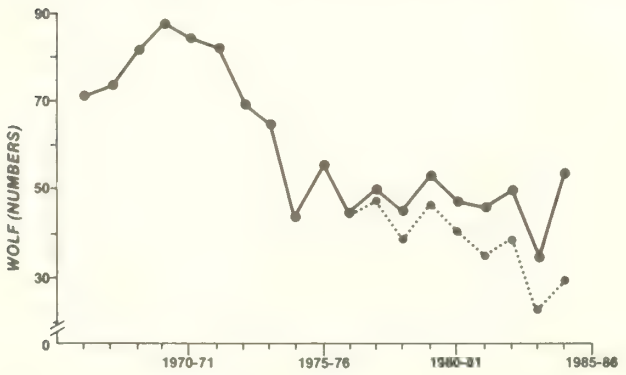

Figure 2.—*Wolf population trend in the central Superior National Forest during winter. Solid line indicates total population in the 2,060-km² study area. About 1976-1977, part of the population began preying primarily on moose during winter. The dotted line represents the trend in number of wolves continuing to prey on deer.*

The fate of the other six members of the original Malberg L. Pack is unknown, except that pups were produced in the north end of the territory, so the pack probably persisted.

Meanwhile by winter 1984-1985, a pack of five including pups, was colonizing the southwestern 20 percent of the 1983-1984 Malberg L. Pack territory and expanding southwestward (Quadga Lake Pack). In addition, the Ensign L. Pack, radioed in spring 1984, numbered seven animals by winter 1984-1985, and preyed primarily on moose. The last time a pack in that area had been radio-tagged (winter 1979-1980) they had migrated out of their territory during winter and preyed on deer several miles westward.

The result of the wolf population's partial switch to a moose economy from 1978 through 1985 was to allow the total population of the study area to remain relatively stable during that period (fig. 2). Meanwhile, the number of deer-killing wolves in the study area continued to decline, although both this subpopulation and the entire population of the study area increased from 1984 to 1985 (fig. 2).

DISCUSSION AND CONCLUSION

The wolf population decline in this study area resulted from a decrease in the wolf's main prey, the white-tailed deer (Mech and Karns 1977). The deer decline ended about 1977, and since then the population has remained low although relatively stable (Nelson and Mech 1986). Nevertheless the wolf population on a deer economy continued to decline for several more years (fig. 2). This fact seems to indi-

cate that at low deer numbers wolves are unable to kill enough deer to enable the wolves to maintain their numbers. Further evidence is found in the switching of part of the wolf population to a moose economy which allowed the wolf population to stabilize in the study area at a density of about 2.3 per 100 km^2 for several years (fig. 2).

It is unknown whether the wolves colonizing the deer-free area in 1978 dispersed from packs on a deer economy and then learned to exploit moose, or whether they came from a moose-killing population to the north. Wolves can disperse distances of at least 866 km (Fritts 1983), but it apparently took several years for wolves to fill the void in the northeastern part of the study area (Mech unpublished) even though dispersers were available from deer-killing wolves to the west and south (Mech in press). The second alternative seems more likely. Although wolves that prey primarily on deer can learn to kill moose (Mech unpublished), there was no indication that this process took place in the northeastern part of the study area.

The wolf population trend in this study area does not necessarily apply to surrounding regions or to the remaining 97 percent of Minnesota wolf range. Because the deer decline itself was localized to the immediate vicinity of the study area (Mech and Karns 1977), wolves throughout most of the rest of their Minnesota range almost certainly were not similarly affected.

Switching of part of the wolf population to a moose economy minimized the effects of a drastic deer decline on wolf numbers. Although extreme fluctuations in both wolves and prey can occur in wolf-moose systems (Peterson *et al*. 1984), the presence of the white-tailed deer as an alternate prey in this study area should help stabilize wolf numbers.

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Research Paper **NC-271**

Deer Population in the Central Superior National Forest, 1967-1985

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DEER POPULATION IN THE CENTRAL SUPERIOR NATIONAL FOREST, 1967-1985

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White-tailed deer (*Odocoileus virginianus*) are an important wildlife resource of the Superior National Forest (SNF). They are not only prized as a game animal by hunters but also highly valued as part of the outdoor experience when viewed by tourists (Lime and Cushwa 1969). Also, deer in this area are the primary prey of the wolf (*Canis lupus*) (Mech and Frenzel 1971), a species classified by the Federal government as threatened in Minnesota. Thus it is important to monitor deer numbers and population trend in the SNF. It is not technically or economically feasible to census deer over large areas of mixed forest, so smaller areas must be used. This report documents the deer population trend from 1976 through 1985 in a part of the central region of the SNF and compares the recent trend with past estimates.

THE STUDY AREA

A main winter concentration area for deer in the central part of the Superior National Forest is the 27 km^2 Isabella deeryard located 6 km northwest of

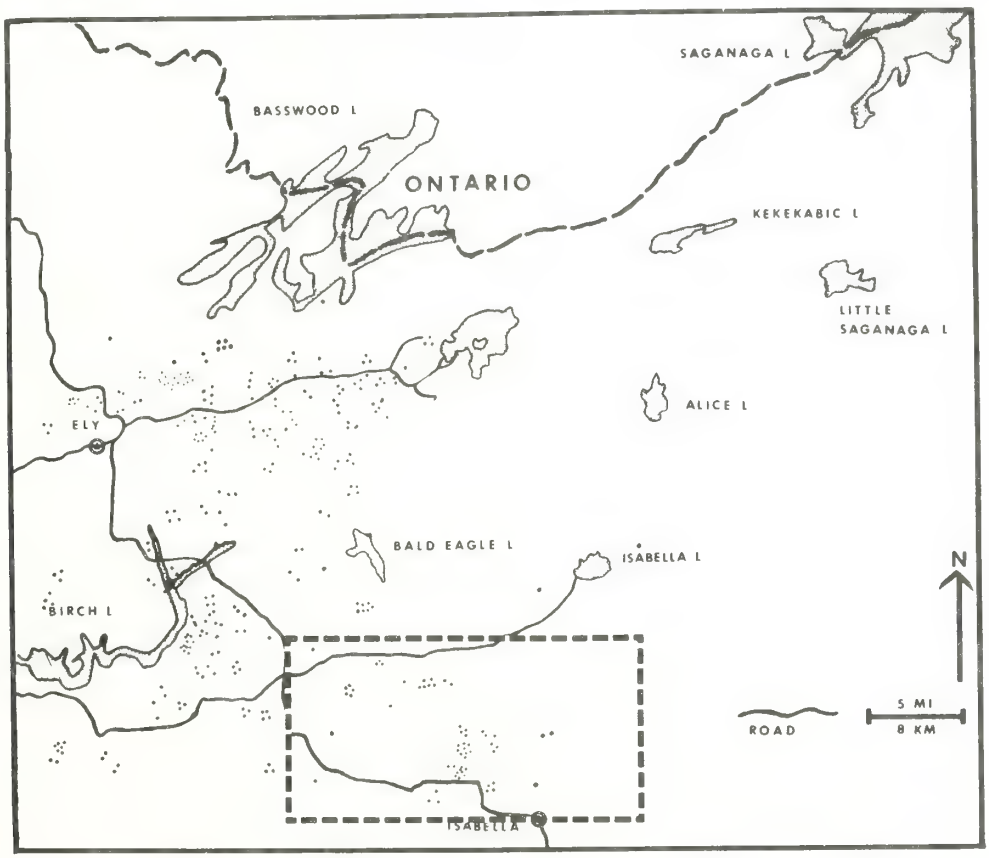

Figure 1.—*Approximate deer distribution, winters 1975-1976 through 1977-1978 based on deer observed from aircraft during wolf radio-tracking. Each dot represents one deer sighting. Dashed zone is the deer census area. Deer seen during censuses are not shown.*

the town of Isabella (Nelson and Mech 1981, In press). In 1976 a 400-km^2 study area was delineated in this region for monitoring deer numbers (fig. 1). The area is characterized by gently rolling terrain (400 to 700 m elevation). The climate is cool-temperate (Hovde 1941), and snowfall averages more than 150 cm during the 5 months of winter, which begins in November. Snow depths range up to 1.1 m.

The vegetation of the study area is a mixture of maturing coniferous-deciduous forests, various aged conifer plantations and clear-cuts from ongoing logging. Aspen (*Populus* spp.), paper birch (*betula papyrifera*), balsam fir (*Abies balsamea*), red pine (*Pinus resinosa*), and jack pine (*Pinus banksiana*) predominate in the uplands. White and black spruce (*Picea glauca* and *mariana*) dominate the lowlands, which comprise less than 30 percent of the area. Much of the area has been logged since 1935 (Peek *et al*. 1976) and is still being logged intensively.

The forests within the Isabella deeryard are predominately aspen-balsam fir and provide an estimated 75 percent of the available winter cover. Mature jackpine (15 percent) and lowland spruce and cedar (*Thuja occidentalis*) (10 percent) comprise the remaining winter cover. During the last 10 years clear-cutting within the deeryard has removed at least 50 percent of the winter cover.

Since 1968, wolf numbers in the "wolf census area" (includes the deer study area and a larger region to the west, north, and northeast) have declined from about 4.2 to 1.7 per 100 km^2 (fig. 1). The 1984-1985 density was 2.6 per 100 km^2 (Mech 1986). Beginning about 1978, the wolves in the northeastern half of the wolf census area switched to killing moose (*Alces alces*), at least in winter. Excluding those animals, the wolves still eating deer in the wolf census area dropped to a density of 2.3 per 100 km^2 in 1978, and reached 1.5 per 100 km^2 in 1984-1985. About 19 percent of adult deer were preyed upon by wolves annually from 1973 through 1984 in this and surrounding areas, and annual yearling recruitment averaged about 30 percent (Nelson and Mech 1986b).

Deer have been hunted legally in the study area throughout the study, but only bucks have been legal since 1974. Mean annual hunting loss of yearling and adult bucks from 1973 through 1984 ranged from 28 to 34 percent (Nelson and Mech 1986b).

METHODS

The method used to census deer in this area since 1976 employed aerially observing deer on 1.6-km^2 sample plots during late winter combined with aerially tracking radio-collared deer to determine deer observability under census conditions (Floyd *et al*. 1979). From 1976 to 1980, we used the sampling procedure outlined by Floyd *et al* (1979), but from 1981 to 1985 all 1.6-km^2 plots containing deer in the study area were counted, generally from 13 to 18 plots comprising the Isabella deeryard. We attempted to use the same aircraft, pilot, and observer for as many years as possible. However, separate observers were used from 1976 to 1978, 1979, and 1980 to 1985, and seven pilots were employed during the study.

Observability factors were determined each year, except 1985, by using known numbers of radio-collared deer observable from the air within the study area or in similar areas nearby. We applied the observability factors in three ways: (1) using each annual factor with that year's data, (2) using the mean observability factors for all years with each individual year, and (3) using the mean observability factor for each observer with all of their respective observations. To gain some idea of how well the deer population trend in the study area represented the trend in the general region, we examined records of deer observed during radio-tracking of wolves in the wolf census area for each year of the study.

RESULTS

During the study, the number of deer observed ranged from 79 to 225 (appendix A) and observability ranged from 35 to 71 percent (table 1). Projected number of deer based on three measures of observability ranged from 158 in 1978 to 457 in 1984 (table 2).

All the deer in the study area concentrated in the Isabella deeryard during the winter (fig. 1), so the

Table 1.—*Correction factors for aerial censuses of deer in the Superior National Forest, Minnesota*

Year	Observer	Known collared deer	Collared deer seen	Proportion seen	Correction factor
		- - - - *Number*- - - -			
1975-1976	A	16	9	0.56	1.78
1976-1977	A	8	4	.50	2.00
1977-1978	A	16	8	.50	2.00
1978-1979	B	31	11	.35	2.82
1979-1980	C	24	17	.71	1.41
1980-1981	C	10	4	.40	2.50
1981-1982	C	24	11	.46	2.17
1982-1983	C	9	6	.67	1.50
1983-1984	C	17	11	.65	1.54
1984-1985	C	no test done	–	–	–

Table 2.—*Aerial deer census of the Isabella study area, winters 1975-1976 through 1984-1985*[1]

Winter	Observer	Counted[2]	Observability		Projected number of deer Method[3]		
			Seen	Correction	A	B	C
		Number	*Percent*				
1975-1976	A	155	56	1.78	276	315	298
1976-1977	A	131	50	2.00	262	266	251
1977-1978	A	79	50	2.00	158	161	186
1978-1979	B	91	35	2.82	258	185	258
1979-1980	C	118	71	1.41	166	240	204
1980-1981	C	112	40	2.50	283	228	194
1981-1982	C	99	46	2.18	216	202	171
1982-1983	C	115	67	1.50	173	234	200
1983-1984	C	225	65	1.54	346	457	389
1984-1985	C	125	–	–	–	254	216

[1]Sampled according to Floyd *et al.* (1979) from 1975-1976 through 1979-1980. All plots containing deer were counted from 1980-1981 through 1984-1985.

[2]First 5 years are projected from sample plots counted; last 5 years include all deer seen because complete count was made.

[3]A = number of deer counted x correction for the same year.
B = number of deer counted x mean correction for all observers for all years.
C = number of deer counted x mean correction for observer.

winter counts apply only directly to the 27-km^2 deeryard area. Winter densities ranged from 5.8 to 16.9 deer km^2 within the yard. During spring, the deer migrate out of the Isabella deeryard to summer ranges, generally northeast, north and northwest (Nelson and Mech 1981). About one-third of the radioed deer left the study area. We have no evidence that deer from other areas migrate into this study area. Thus an approximate summer density for the entire study area is from 0.3 to 0.7 deer km^2 during the study.

DISCUSSION

We are confident that most deer in the study area wintered in the Isabella deeryard even during mild winters. Radio-collared deer migrated to the deeryard during mild and severe winters alike, and weekly reconnaisance flights did not discover wintering deer elsewhere. Observations by loggers, foresters, and other biologists working in the area supported our observations. Radio-collared deer from two nearby deeryards also migrated from summer ranges each year regardless of severity of winter (Nelson and Mech 1981, and unpubl. data).

It is debatable which of our observability calculations best estimate the deer population. Regardless of whichever is used, however, the results are reasonably similar (table 2). They indicate that the deer decline in the late 1960's and early 1970's (Mech and Karns 1977) ended about winter 1977-1978 and that the deer population remained stable from then until it increased substantially in winter 1983-1984. Further evidence of the increase came from general observations at private artificial feeding operations in the Isabella deeryard and in the Garden Lake deeryard 38 km to the northwest; at the Garden Lake yard approximately twice as many deer were observed in 1984 as in any recent previous year.

The 1985 census probably underestimated deer because a new, less experienced pilot was used and snow conditions were marginal for counting. Thus the apparent decline from 1984 to 1985 may not have been as great as the data suggest.

Private artificial feeding began in the Isabella deeryard in 1982 and still continues. It is not known to what extent this has contributed to the increase in deer numbers. Artificial feeding increased productivity, body weights, and deer numbers in a semicaptive Michigan herd subject to similar climatic conditions (Ozoga and Verme 1982). However, in 1983 deer populations also increased outside our study area and in areas with no artificial feeding.

Conceivably, the mild winter of 1982-1983 could have contributed substantially to the deer increase the following year. Improved fetal development and thus increased fawn weights and survival are direct results of mild winters (Verme 1977). In addition, adult survival would have increased because wolves kill fewer deer in mild winters Nelson and Mech 1986a). Mortality from malnutrition would have been less also, although that was not a major cause of death during our study (Nelson and Mech 1986b).

The first quantitative data concerning deer numbers in the study area come from drive censuses conducted from 1936 through 1939 (Olson 1938, Fredine 1940). Drive counts of 2.6-km^2 plots by crews of 100 men ranged from 4 to 9 deer/km^2. Later, estimates for the surrounding area indicated that the population may have been approximately 3.5 deer/km^2 in 1953 (Stenlund 1955) and that it remained at about that order of magnitude through 1967-1968 (Mech, unpubl. data). The herd then declined drastically, and the present census apparently records the last few years of the decline. A gross approximation of the deer population trend in the study area for 1967-1985 is given in figure 2.

In the region northwest of the deer census area, the trend in complete loss of overwintering deer documented by Mech and Karns (1977) from 1968 through 1974 apparently continued for several more years. By winter 1977-1978, the few individuals left northeast of Bald Eagle Lake were gone as were those in the northern half of the Isabella study area

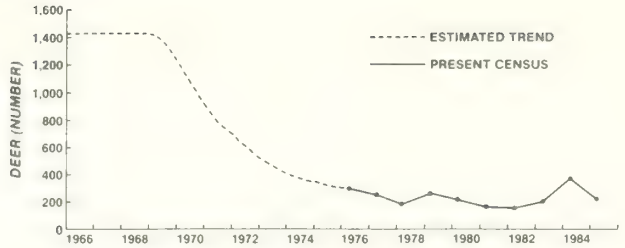

Figure 2.—*Approximate trend in deer population of the census area.*

(cf. fig. 8 in Mech and Karns 1977 with fig. 1 this publication). From then through winter 1980-1981, several deer northwest of Bald Eagle Lake were lost (cf. fig. 1 and fig. 3). Between then and winter 1984-1985 overwintering deer disappeared from the area within 13 km north to northwest of Bald Eagle Lake, (cf. fig. 3 and fig. 4). As documented earlier (Mech and Karns 1977), these deer were killed by wolves, with severe winters as an underlying factor.

The continuing disappearance of deer in the region after winter 1977-1978 seems to contradict the trend in the Isabella deer herd, which apparently stabilized after that winter and eventually increased (fig. 2). This inconsistency could represent intrinsic individual variation because individual deer herds within the general population of the region are basically discrete and variable in many important respects (Nelson and Mech In press). However, the main reason the Isabella herd persists probably is because of its migratory and yarding behavior and the fact that the Isabella deeryard is located within a few kilometers of human habitations, both of which reduce the risk of wolf predation (Nelson and Mech 1981). The deer herds still being decimated are those that are more dispersed, nonyarded deer living in remote areas.

The interactions between wolf predation, snow accumulation, yarding, and proximity to human habitations, are complex and still under study (Nelson and Mech 1981, 1986a,b).

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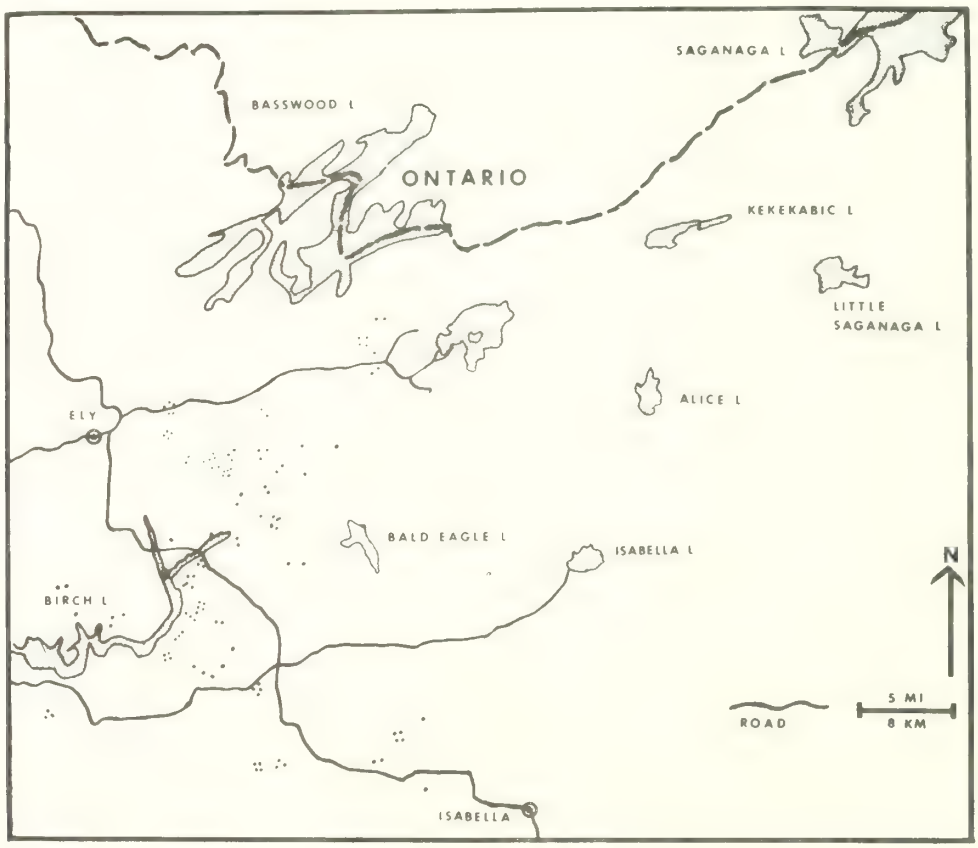

Figure 3.—*Approximate deer distribution, winters 1978-1979 through 1980-1981 based on deer observed from aircraft during wolf radio-tracking. Each dot represents one deer sighting.*

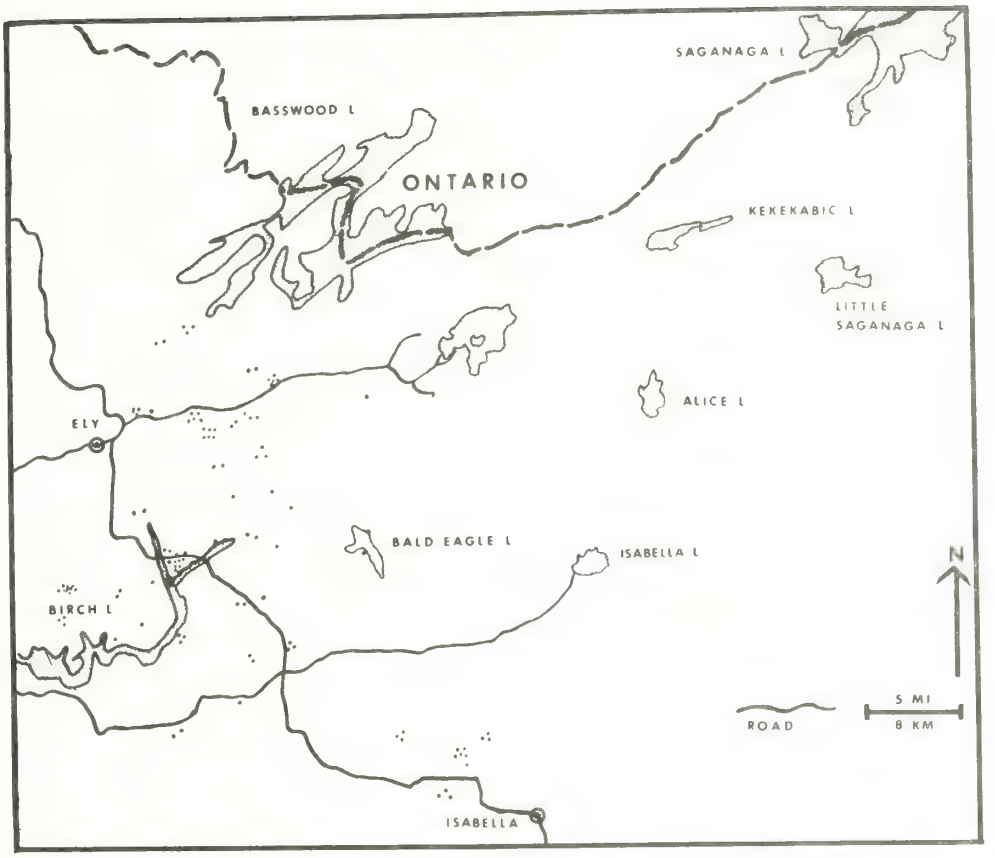

Figure 4.—*Approximate deer distribution, winter 1981-1982 through 1984-1985 based on deer observed from aircraft during wolf radio-tracking. Each dot represents one deer sighting.*

ment of Interior, Fish and Wildlife Service; and the U.S. Department of Agriculture North Central Forest Experiment Station. We especially appreciate the support of Clay G. Beal, Forest Supervisor, and Ed Lindquist, forest biologist. Numerous technicians, volunteers, and students assisted with live-trapping and radio-tagging the deer, and many bush pilots provided skillful flying. We especially appreciate the help of J. Renneberg, S. T. Knick, J. Burch, D. Mahl, J. Ortmann, Jr., K. Jouppi, D. Glaser, and D. Monson. The Minnesota Department of Natural Resources granted approvals, permits, and miscellaneous support and encouragement. J. M. Sweeney made several helpful suggestions for improving the manuscript.

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Appendix A.—*Number of deer observed according to plot in the Isabella deer census area, 1976-1985*[1]

Plot			Inside (I) or adjacent (A) to deeryard	Census data									
Range	Township	Section		1976[2]	1/25-2/11 1977	2/13-3/3 1978	2/8-3/16 1979	2/12-28 1980	2/25-3/4 1981	3/9-22 1982	2/17-25 1983	2/21-3/16 1984	2/19-3/12 1985
61	9	24		2									
61	10	25		1				0					
61	9	31		4									
61	9	34		5	0								
61	8	31		3	3	0	0	0					
61	8	33		0	3			0	0				
60	10	5		5	0	1							
60	10	4				7							
60	10	1			2		0	0					
60	9	1		3	4			0					
60	10	11		4									
60	10	12		2	4		0						
60	10	14			6								
60	10	13			3							1	
60	9	18				0		1	0				
60	9	17				0	0	9					
60	9	16				0	1						
60	9	15	A				2	2				7	
60	9	19				0		6	0				
60	9	20	A		2	0		3				5	0
60	9	21	A			3		2			10	0	
60	9	22	I		8	9	14	3	10	15	9	30	24
60	9	23	I	0		4	0	3	11	0	7	13	6
60	9	24	A				0						2
60	8	19		2			0						
60	8	21		2									
60	10	25				1	1		0				
60	9	29	A		2	0			4			3	0
60	9	28	I			7		9	13	8	7	3	11
60	9	27	I	0			18	16	17	37	22	48	46
60	9	26	I		5	25	23	15	12	0	20	44	2
60	9	25	A		0			0	0		5	6	6
60	9	32	A			3						20	1
60	9	33	I			7		4	15	6	8	20	11
60	9	34	I			0	5	16	23	23	14	23	3
60	9	35	I	9		2	0	8	4	5	5	0	0
60	9	36	A		0	0	0	2	1		8	2	6
60	8	31		3	1	0	0			5			7
60	8	32					1	0					
60	8	33		6									
59	9	1	A		12				2			0	
Number of plots				45	45	40	40	35	21	9	11	17	15
Number of deer seen				51	55	69	65	99	112	99	115	225	125

[1]Population estimates for 1976-1980 based on sampling, according to Floyd *et al*. (1979); 1981-1985, total count of all plots containing deer; 1976-1978 observer T. Floyd; 1979 observer J. Renneberg; 1980-1985 observer M. Nelson.

[2]Census date 12/7/75 to 4/1/76.

1966-86

NORTH CENTRAL

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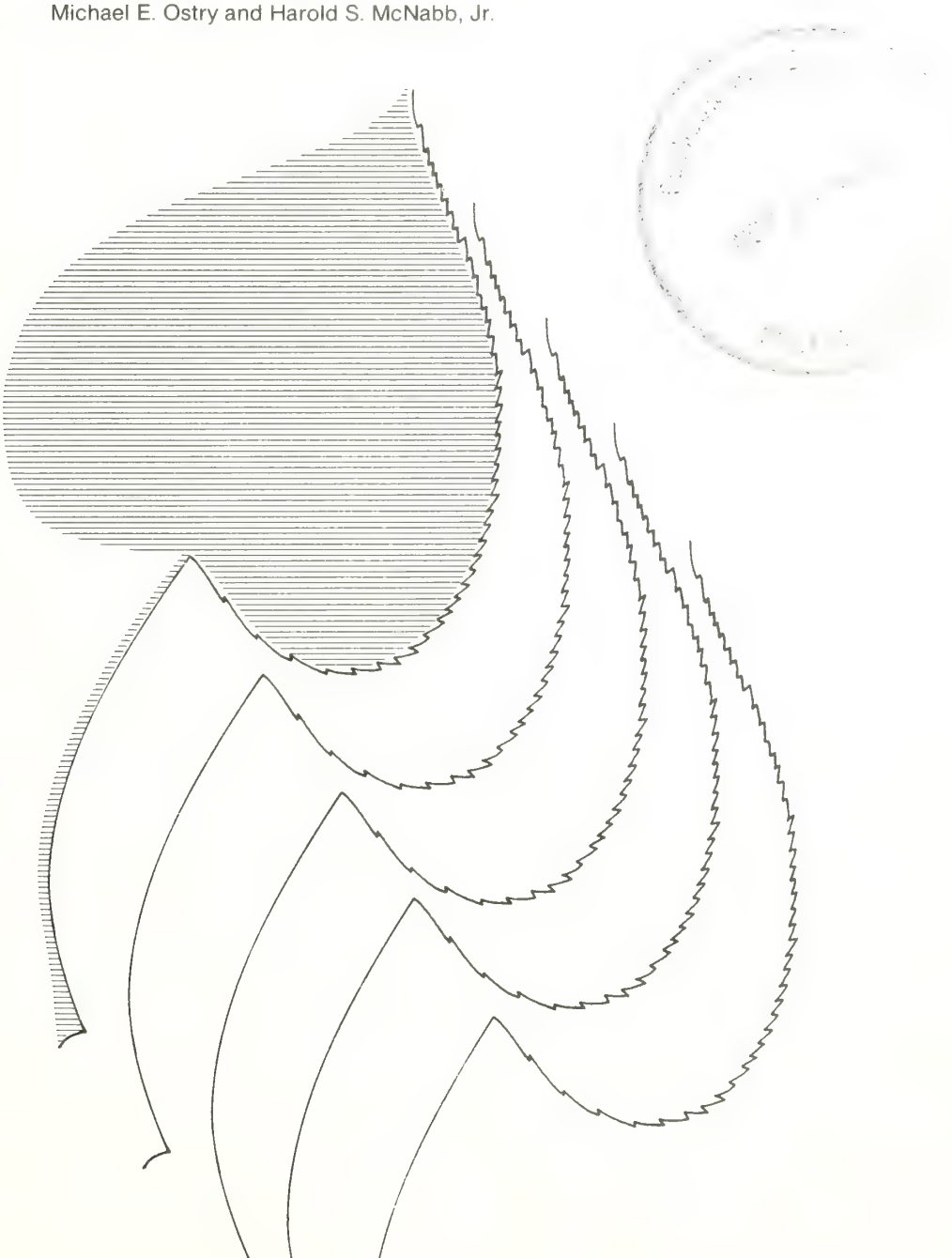
Research Paper **NC-272**

Populus Species and Hybrid Clones Resistant to Melampsora, Marssonia, and Septoria

Michael E. Ostry and Harold S. McNabb, Jr.



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1986

POPULUS SPECIES AND HYBRID CLONES RESISTANT TO *MELAMPSORA*, *MARSSONINA*, AND *SEPTORIA*[1]

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Planting hybrid poplars has increased in recent years in the north central United States. Unfortunately, many of the hybrids that have been planted are highly susceptible to several damaging diseases and few studies have been done to test their susceptibility to the diseases prevalent in the area (Schipper 1976, Ostry and McNabb 1985). Leaf rust caused by *Melampsora medusae* Thuem., leaf spot and shoot lesion caused by *Marssonina brunnea* (Ell. and Ev.) Magn., and leaf spot and canker caused by *Septoria musiva* Peck are major threats to poplar production in the north central United States (Ostry and McNabb 1983). Selecting clones with high levels of resistance to these pathogens is the most desirable form of disease control (Ostry and McNabb 1983, Widen and Schipper 1981, Castellani and Cellerino 1964). Therefore, successfully establishing and managing high-yielding poplar plantations in the north central U.S. will depend upon planting clones that are resistant to these major pathogens. This study was undertaken to screen the *Populus* selections and hybrids that have been developed during the last four decades for resistance to *M. medusae, M. brunnea*, and *S. musiva*.

MATERIALS AND METHODS

Dormant hardwood cuttings from 499 *Populus* clones representing 40 hybrids and species were provided by the following people: Mr. Allan Allyn, Consolidated Packaging Corp., Ft. Madison, IA; Dr. Robert Stack, Department of Plant Pathology, North Dakota State University, Fargo, ND; Dr. Walter Bagley, University of Nebraska, Lincoln, NE; Dr. Louis Zsuffa, Canada Ministry of Natural Resources, Maple, Ontario; and Dr. M. E. Demeritt, Northeastern Forest Experiment Station, Durham, NH.

Plantations were established in 1978 near Rhinelander, WI; Rosemount, MN; and Rhodes, IA. The Rhinelander site was prepared by plowing and roto-tilling. The sites at Rosemount and Rhodes were prepared by plowing, disking, and applying Treflan®[2]. Ten cuttings of each clone were planted at 0.3 m spacing within rows and 2.8 m between rows—at Rhinelander, however, spacing between rows was 1.2 m. Clones were not replicated within plantations. Weeds were controlled with Roundup® for the first 2 years and by mowing thereafter at Rosemount and Rhodes. At Rhinelander Roundup® was used until the crowns closed and reduced weed competition. Trees were irrigated with a trickle irrigation system at Rhinelander only.

Trees were evaluated for disease severity three times each year from 1979 through 1981. A scale of 0 (absent or trace) to 3 (premature defoliation) was used to rate foliar diseases. Branch and stem cankers caused by *S. musiva* were rated as either 0 (absent) or 1 (present). The final score was based on the ratings from all 3 years. Tree survival and height were recorded in September 1981.

RESULTS AND DISCUSSION

Results of this study clearly illustrate the importance of selecting disease-resistant *Populus* clones for planting in the north central United States. Resistance to *Melampsora, Marssonina*, and *Septoria* differed greatly among the *Populus* species and hybrids tested (tables 1 and 2). Many clones were found unsuitable because of their susceptibilty to one or more diseases. Some clones were affected by all three pathogens, however, one usually predominated. Incidence and severity of *Melampsora* remained constant from year to year. By contrast, *Marssonina* and *Septoria* increased in severity each year.

[1]*Journal Paper J-12045 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Projects 2210 and 2524.*

[2]*Mention of trade names does not constitute endorsement by the USDA Forest Service.*

Table 1.--Disease ratings[1/], mean height growth, and mean survival of 150 Populus clones representing 38 hybrids, one named selection of the species P. deltoides, and one named selection of P. nigra growing in Minnesota, Iowa, and Wisconsin plantations 1979-1981

Number of clones	Hybrid parentage or species selection	Septoria leaf spot	Septoria canker	Marssonina leaf spot	Melampsora leaf rust	Height class[2/] MN	IA	WI	Mean survival (%) MN	IA	WI
8	P. nigra X P. laurifolia	1-3	1	2-3	0-1	5	4	9	41	76	72
3	P. nigra X P. trichocarpa	1-2	1	3	1-2	7	6	10	37	43	64
10	P. nigra var. Charkowiensis X P. nigra var. caudina	0-3	1	1-3	0-3	7	8	9	67	80	54
2	P. nigra var. Charkowiensis X P. nigra Incrassata	1-2	1	2	1	6	7	9	65	85	55
3	P. nigra var. Charkowiensis X P. deltoides	0-2	1	1-2	0-1	8	9	9	75	85	60
1	P. nigra var. Charkowiensis X (P. X berolinensis)	1-2	1	2	1	5	5	10	60	100	80
1	P. nigra var. Charkowiensis X (P. euramericana Robusta)	0-1	0	2	1	9	10	6	90	90	60
5	P. nigra var. Charkowiensis X P. trichocarpa	1-2	1	1-3	1	7	6	10	75	88	54
1	P. nigra var. betulifolia X P. trichocarpa Andover	1	1	3	1	5	--	9	29	--	71
1	P. nigra X (P X euramericana Eugenii)	1-2	0	3	1[3/]	9	8	--	57	86	--
6	P. nigra var. betulifolia X P. trichocarpa	1-2	0-1	2-3	1	8	5	9	85	80	79
3	P. nigra var. betulifolia X P. nigra Volga	1-2	0-1	1-2	0-1	8	9	6	77	70	50
1	P. nigra var. Italica Lombardy	0-1	0	0	1	5	6	10	22	78	89
3	P. maximowiczii X P. trichocarpa	1-2	0-1	0-2	1	5	4	10	53	63	54
5	P. maximowiczii X (P. X berolinensis)	1-2	0-1	1-3	1	6	5	10	69	71	73
1	P. maximowiczii X P. nigra var. plantierensis	1	1	0	1	7	5	11	43	83	86
1	P. Baatanicorum Vitrum X P. nigra Volga	0-1	1	1	1	6	7	6	56	100	33
2	P. Baatanicorum Vitrum X P. trichocarpa	2	0-1	2-3	1	5	5	8	60	55	50
1	(P. X Petrowskyana) X P. nigra var. caudina	1-2	1	3	2	6	6	9	80	60	60
1	(P. Rasumowskyana) X P. nigra var. caudina	1	1	2	1	4	3	10	90	90	80
9	P. candicans X (P. X berolinensis)	1-2	0-1	2-3	1	6	4	10	66	61	58
2	P. simonii X (P. X berolinensis)	1	0-1	1-3	1	9	6	4	75	60	55

(Table 1. continued)

Number of clones	Hybrid parentage or species selection	Septoria leaf spot	Septoria canker	Marssonina leaf spot	Melampsora leaf rust	Height class[2/] MN	IA	WI	Mean survival (%) MN	IA	WI
1	P. balsamifera X P. deltoides Jackii 4	0-1	0	2	1	7	6	4	70	30	70
9	P. X euramericana	0-1	0	2-3	1-2	9	8	7	36	88	58
22	P. deltoides X P. trichocarpa	1-3	1	1-3	1-3	5	6	6	43	73	37
1	P. deltoides var. occidentalis Sargentii X P. nigra Italica	1	1	1	1	--	5	6	--	44	30
2	P. deltoides var. occidentalis Sargentii X (P. berolinensis) Rossica	1-2	1	1-2	1	4	4	10	52	65	66
1	P. deltoides var. occidentalis Sargentii X P. simonii	0-1	0	2	2	4	5	4	30	70	30
16	P. deltoides X P. nigra var. caudina	0-1	0-1	1-3	1-2	8	8	8	68	79	62
2	P. deltoides X P. nigra Volga	0-1	0-1	2-3	1	7	7	5	60	75	57
2	P. deltoides X P. nigra var. plantierensis	1	1	2-3	1	5	7	8	45	63	34
1	P. deltoides var. occidentalis X P. balsamifera Northwest	1	0-1	1	3	3	3	3	60	100	50
1	P. deltoides X P. grandidentata	1	1	2	1	--	9	4	--	80	60
1	P. deltoides Siouxland	1	1	1	1	--	6	10	--	50	70
11	P. deltoides var. angulata X P. trichocarpa	1-3	1	2-3	2-3	6	7	7	50	67	50
2	P. deltoides var. angulata X P. nigra Volga	0-1	0	3	1	6	6	10	55	35	55
2	P. deltoides var. angulata X P. deltoides	1	0	1-3	1	7	4	9	27	20	20
2	P. deltoides var. angulata X (P. X berolinensis)	1-2	0-1	2-3	1-2	5	7	11	34	62	39
2	P. deltoides var. angulata X P. nigra Incrassata	1-2	0-1	1-2	1	6	6	9	40	62	15
2	P. deltoides var. angulata X P. nigra var. plantierensis	0-1	0-1	3	1	4	7	8	40	95	80

[1/] Marssonina ratings based on data from all three locations, Septoria on data from Minnesota and Iowa, and Melampsora from Wisconsin data. A range is given to indicate variation among clones within a hybrid or between plantations in the case of species clones.

Foliar Disease Rating
0 = Absent or trace
1 = Slight, lower crown only
2 = Medium, throughout crown, defoliation in lower crown only
3 = Severe, defoliation throughout crown

Canker Rating
0 = Absent
1 = Branch and stem cankers

[2/] Height Class (m)
1 = 0.10 - 0.50
2 = 0.51 - 1.00
3 = 1.01 - 1.50
4 = 1.51 - 2.00
5 = 2.01 - 2.50
6 = 2.51 - 3.00
7 = 3.01 - 3.50
8 = 3.51 - 4.00
9 = 4.01 - 4.50
10 = 4.51 - 5.00
11 = 5.01 - 5.50

Table 2.--Disease ratings[1/], mean height growth, and mean survival of 11 Populus deltoides provenances growing in Minnesota, Iowa, and Wisconsin plantations 1979-1981

Provenance	Number of families	Number of clones	Marssonina leaf spot	Melampsora leaf rust	Height class[2/] MN	IA	WI	Mean survival (%) MN	IA	WI
Minnesota	26	103	1-2	1-2	6	6	7	38	54	25
Wisconsin	2	6	2	2	7	5	8	44	49	29
South Dakota	1	5	1	3	5	2	-	27	3	0
Northern Illinois	24	71	0-2	1	6	4	6	32	32	29
Nebraska	8	30	1-2	1-2	4	4	3	18	34	3
Pennsylvania	1	3	1	1	5	4	7	67	63	30
Ohio	11	35	1	0-2	5	4	8	36	40	24
Indiana	5	21	1	0	6	5	7	43	56	32
Missouri	16	56	0-1	1-2	6	4	6	36	19	9
Kansas	3	10	1	1	4	3	3	44	9	7
Southern Illinois	6	9	0-1	1-3	7	4	7	21	2	12

[1/] Marssonina ratings based on data from all three locations, Melampsora ratings based on data from Rhinelander. A range is given to indicate variation within families. Severity of Septoria leaf spot was minor and Septoria canker was absent.

Foliar Disease Rating

0 = Absent or trace
1 = Slight, lower crown only
2 = Medium, throughout crown, defoliation in lower crown only
3 = Severe, defoliation throughout crown

[2/] Height Class (m)

1 = 0.10 - 0.50
2 = 0.51 - 1.00
3 = 1.01 - 1.50
4 = 1.51 - 2.00
5 = 2.01 - 2.50
6 = 2.51 - 3.00
7 = 3.01 - 3.50
8 = 3.51 - 4.00
9 = 4.01 - 4.50
10 = 4.51 - 5.00
11 = 5.01 - 5.50

Survival and growth of hybrid poplar clones were generally greater than that of the *P. deltoides* clones at all locations (tables 1 and 2). Early tree mortality was attributed to planting failure and winter injury. Subsequent mortality of many of the hybrid clones was due to stem breakage at Septoria cankers or girdling by stress-related fungi such as *Cytospora chrysosperma* (Pers.) Fr., *Phomopsis macrospora* Kobayashi and Chiba or *Dothichiza populea* Sacc. & Br. Survival of the *P. deltoides* clones was poor, however, their greater resistance to Septoria leaf spot and canker sharply contrasted the majority of the hybrid poplars tested.

This study was designed to obtain information on disease severity but not to determine the growth potential of individual clones. Therefore, height classes are given only to serve as a general guide to the productivity of each clone under existing test conditions. Tree growth generally was greater at Rhinelander for most *P. deltoides* and hybrid clones than at either Rosemount or Rhodes. This result was attributed to irrigation and intensive weed control at Rhinelander.

Incidence and severity of two of the three diseases studied differed greatly among the test sites. *Melampsora* leaf rust was most severe at Rhinelander where *Larix laricina*, the alternate host for *M. medusae*, was present. Disease symptoms were visible 2 months sooner on susceptible clones at Rhinelander than at either Rosemount or Rhodes. Highly susceptible clones usually defoliated completely by mid-August at Rhinelander. Mortality of severely affected clones was high. These same clones were only slightly affected in September at Rosemount and Rhodes.

Septoria leaf spot and canker was far more severe at Rhodes and Rosemount than at Rhinelander where leaf spot was slight and canker absent until 1983. Septoria canker was first detected in 1981 in other *Populus* test plantings near Rhinelander. Since then, Septoria canker has increased in severity to about the same level as at Rhodes and Rosemount.

Marssonina was common on susceptible clones at all three locations and caused severe premature defoliation and shoot lesions on some clones. Unlike *Melampsora* and *Septoria*, no major difference was detected in disease severity at the three sites.

Cankers caused by *Hypoxylon mammatum* (Wahl.) Mill. were found on two trees of two hybrid clones at Rosemount. The two hybrids were *P. nigra* var. *betulifolia* X *P. nigra* 'Volga' and *P. nigra* var. *betulifolia* X *P. trichocarpa*. Trees of three additional hybrid clones have been infected by *Hypoxylon* in commercial plantings in Michigan. Clones affected were *P. maximowiczii* X (*P.* X *berolinensis*), *P. candicans*' X (*P.* X *berolinensis*), and *P. deltoides* X *P. nigra* 'Incrassata' (Ostry, unpublished data). It is not known what the potential impact of this pathogen will be on these hybrids or how widespread the incidence of this disease will be in future plantations.

Variation across sites in tree survival and in the incidence and severity of diseases among the clones means that clones need to be evaluated under a wide range of field conditions at several locations before recommendations can be made on their growth potential and disease resistance. Careful consideration must be given to where test plantations are located and what pathogens are important in that area in order to accurately assess a clone's resistance to a specific pathogen.

Hybrid clones with *P. trichocarpa, P. laurifolia*, or *P. maximowiczii* as one parent were the most susceptible to Septoria canker. In contrast, cankers were found on only one *P. deltoides* clone. However, Septoria canker is considered a serious problem on *P. deltoides* in the southern United States (Filer *et al.* 1971).

Many of the hybrids evaluated in this study previously had been rated for resistance to *Septoria* during their selection in the northeastern United States. Clones in that trial that were susceptible to canker but produced high volumes of wood were not discarded because of the belief that they would be suitable for mini-rotation management (Schreiner 1971). Results of this study indicate that this strategy will not work in the north central region. Susceptible clones should not be grown in this region even under short rotation management because of the potential impact of *S. musiva*.

Susceptibility to Septoria canker differed little within a parental type at a particular location. Hybrids with one or both parents belonging to the section Tacamahaca were uniformly susceptible to *Septoria*. The 38 hybrids tested included 148 clones. Twenty hybrids were free from Septoria canker at either Rosemount or Rhodes or at both locations. From this group, 24 clones (16 percent) were free from canker at Rosemount and Rhodes. An additional 13 clones (9 percent) had cankers at only one location. Included in this second group were a few clones with no surviving trees at one location because of planting failure. The remainder of the hybrid clones had cankers at both locations.

Of the hybrids tested, the *P.* X *euramericana* clones were the most resistant to *Septoria*. However, among these clones were some that could not be recommended because of their high susceptibility to *Marssonina*. These clones commonly defoliated prematurely and diedback.

Although clones were rated for the leaf rust caused by *M. medusae*, evidence exists that at least two other *Melampsora* species or intermediate types exist in the north central region (Stack and Ostry 1983). Recent reports indicate that host-specific races of *Melampsora* exist in Australia and in Europe (Chandrashekar and Heather 1980, Singh and Heather 1982, Pinon and Bachacou 1984). Thus, it is important for *Populus* breeders and growers to continue monitoring for leaf rust, especially on clones that have previously been free from disease.

Results of this study and that of McNabb *et al.* (1982) indicate that clones susceptible to Septoria canker cannot be managed successfully in short rotation (5 to 15 year) fiber-production plantations. Therefore, it is important that resistance to *S. musiva* be included in *Populus* selection and breeding programs. In addition, clones should not be released for commercial trade until they have been thoroughly tested for disease resistance in the areas where they will be grown. Persons interested in growing hybrid poplars should obtain the original clone number as well as varietal or cultivar name of available planting stock so that inquiry can be made as to its disease resistance before purchase.

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Ostry, Michael E.; McNabb, Harold S., Jr.
Populus species and hybrid clones resistant to *Melampsora, Marssonina*, and *Septoria*. Res. Pap. NC-272. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 7 p.

Trees were rated for their resistance to the foliar pathogens *Melampsora medusae* and *Marssonina brunnea* and the foliar and canker pathogen *Septoria musiva*. Many clones were found to be too susceptible to one or more diseases to be safely planted in the north central United States. The *P. X euramericana* clones were the most resistant to *Septoria*.

KEY WORDS: *Septoria musiva, Melampsora medusae, Marssonina brunnea*, intensive culture.

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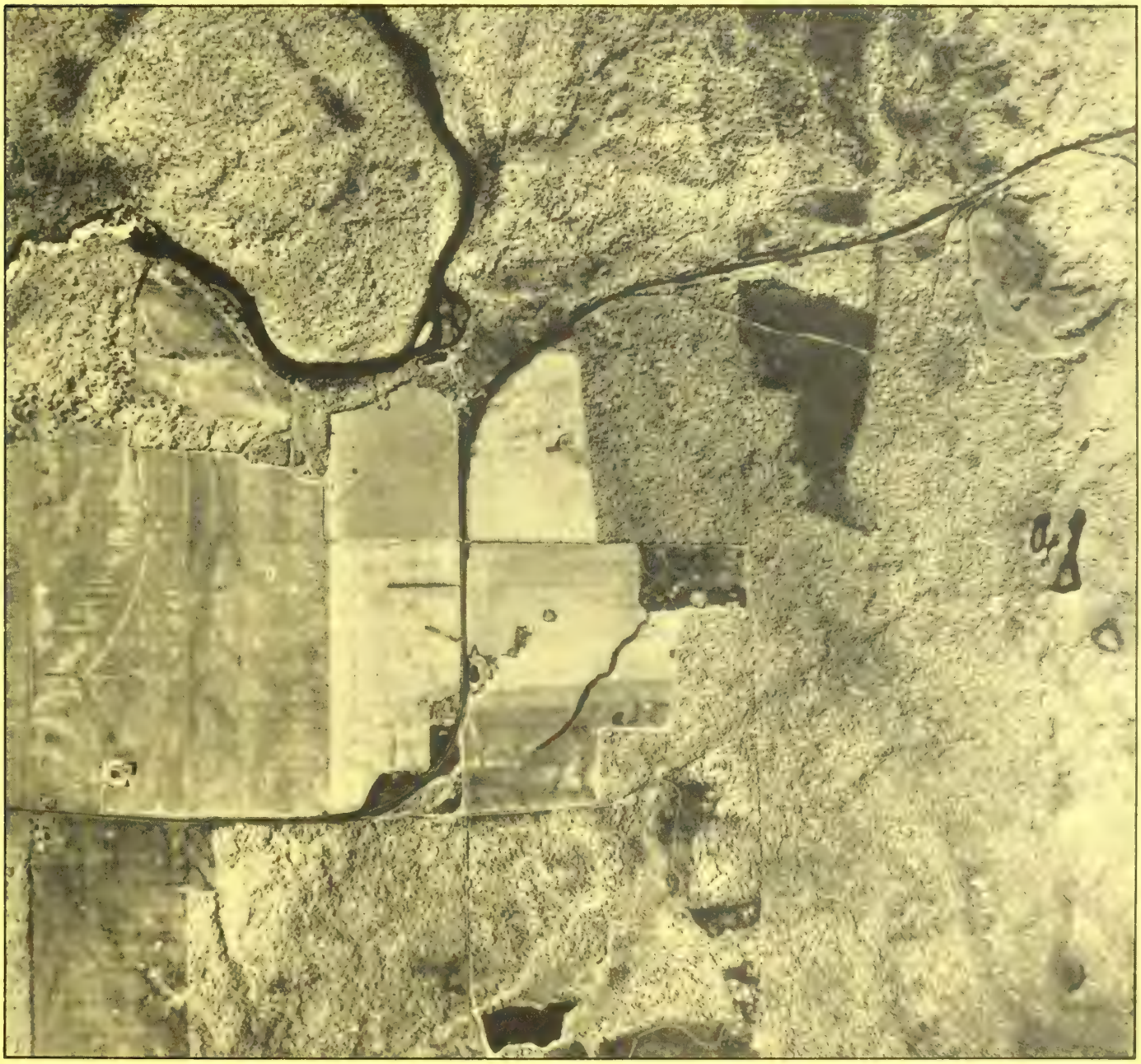
A Method for Estimating Operability and Location of the Timber Resource

John S. Spencer, Jr., Mark H. Hansen, and Pamela J. Jakes



CONTENTS

	Page
Methods	1
Discussion	5
Results for Minnesota	6
Appendix	10
Principal Tree Species Groups in Minnesota	10
Metric Equivalents of Units Used in This Report	10
Universal Transverse Mercator (UTM) Grid System	10
Definition of Terms	11
Tables	13

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A METHOD FOR ESTIMATING OPERABILITY AND LOCATION OF THE TIMBER RESOURCE

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Mark H. Hansen, *Biometrician*,
and **Pamela J. Jakes**, *Principal Forest Economist*

Minnesota's 13.7 million acres of timberland in 1977[1] supported 11.5 billion cubic feet of growing stock[2]. Some of this material is unavailable to potential timber purchasers because landowners do not presently wish to sell their timber. Additional volume may be unavailable for harvesting or management due to operability. We define operability as the relative ease or difficulty of managing or harvesting timber because of physical conditions in the stand or on the site. Operability problems include small average tree size, fragile soils, poor drainage, inaccessibility, and small tract size, among others.

The primary purpose of this paper is to describe a method for evaluating the operability of timberland in a large geographic area, such as a State, using information collected during Statewide forest inventories. A secondary objective is to discuss the operability information generated for Minnesota.

Statewide inventory information was provided by Forest Inventory and Analysis (FIA) permanent sample plots. Although some subjectivity was involved in assigning values to operability components, the use of FIA data guarantees objectivity in the calculation of areas and volumes by operability classes. Users of this information can also mitigate some of this subjectivity by employing a method we've devised for tailoring the results to more closely fit his or her requirements. Up to three of the seven operability characteristics used to stratify areas into operability classes can be eliminated, and the remaining characteristics—those deemed important to the user—can be used alone to estimate operability class.

[1]*Jakes, Pamela J. The fourth Minnesota forest inventory: area. Resour. Bull. NC-54. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1980. 37 p.*

[2]*Spencer, John S., Jr. The fourth Minnesota forest inventory: timber volumes and projections of timber supply. Resour. Bull. NC-57. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 72 p.*

METHODS

The method used to develop operability classes for Minnesota's timberland consisted of seven basic steps (fig. 1).

1. *Select Operability Class Components*

Information collected during Statewide forest inventories falls into two categories—tree data and stand data. Tree data include species, diameter at breast height (d.b.h.), merchantable height, log grade, and other items. Tree measurements are used to compute basic inventory statistics such as timber volume, growth, and quality. Stand data collected include site index, stand age, forest type, stand area, owner, distance to water and roads, and other items. Stand information complements tree data and allows for a more complete analysis of basic inventory data.

Information used to define operability classes in Minnesota was selected from tree and stand data collected during the 1977 State inventory. We asked representatives from the public and private sectors of forestry to identify tree and stand data they deemed important in determining operability. Although they identified numerous factors, we narrowed the list to those most frequently identified and those for which information was available from FIA plots. Our final list consisted of seven major operability components: stand area, growing-stock volume per acre, sawtimber volume per acre, percent of cull trees in the stand, average diameter at breast height (d.b.h.) of growing-stock trees, merchantable

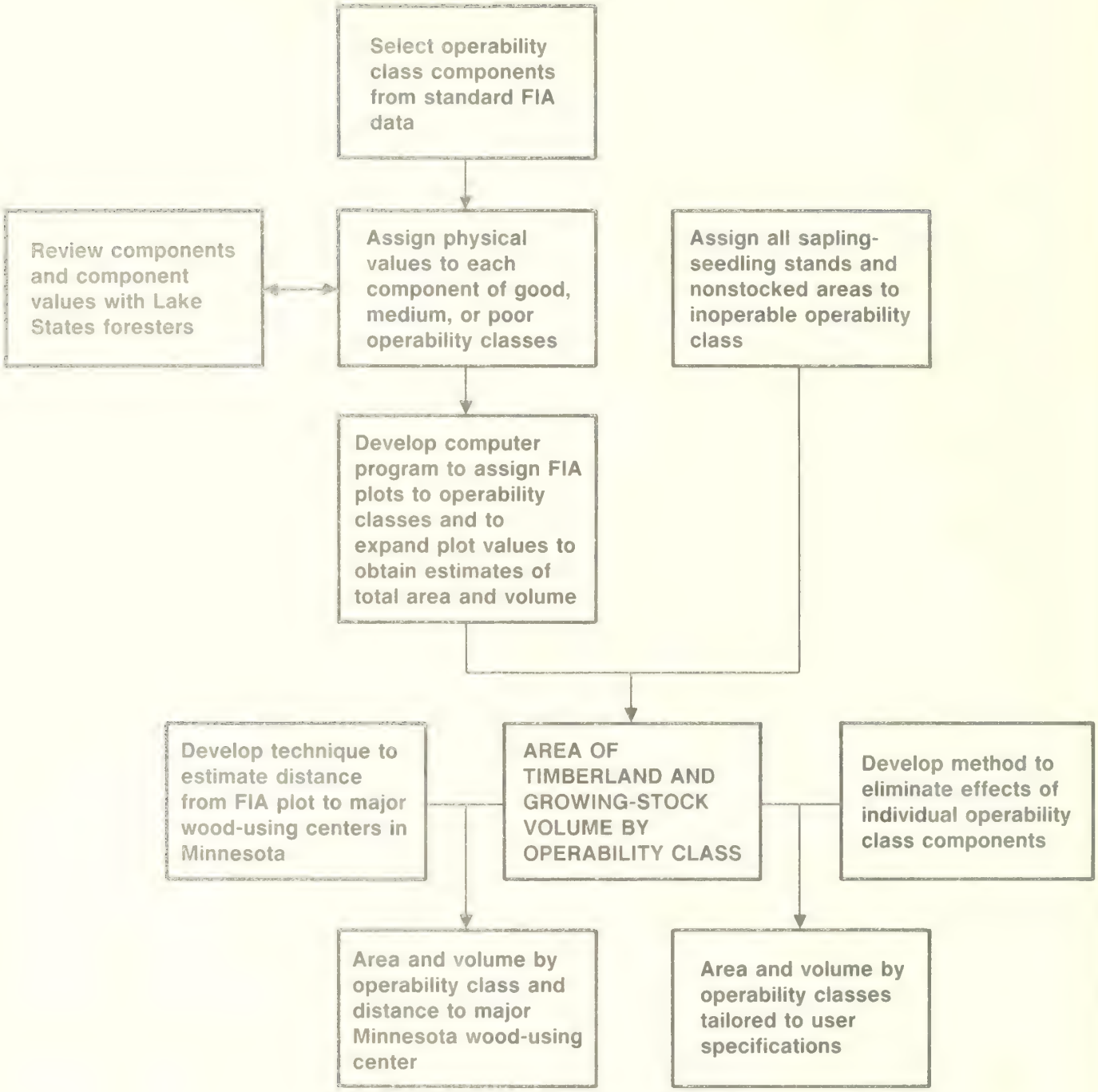
Select operability class components from standard FIA data
Review components and component values with Lake States foresters
Assign physical values to each component of good, medium, or poor operability classes
Assign all sapling-seedling stands and nonstocked areas to inoperable operability class
Develop computer program to assign FIA plots to operability classes and to expand plot values to obtain estimates of total area and volume
Develop technique to estimate distance from FIA plot to major wood-using centers in Minnesota
AREA OF TIMBERLAND AND GROWING-STOCK VOLUME BY OPERABILITY CLASS
Develop method to eliminate effects of individual operability class components
Area and volume by operability class and distance to major Minnesota wood-using center
Area and volume by operability classes tailored to user specifications

Figure 1.—*Method for determining Minnesota's timberland operability.*

height of growing-stock trees, and distance to a maintained[3] road from the stand.

2. *Assign Physical Values to Components*

Based on information collected during interviews and through a literature search, we assigned physical values to each of the seven operability components separating the values of each component into three operability classes (good, medium, and poor).

[3]*See Definitions of Terms in Appendix.*

3. *Segregate Sapling-Seedling Stands and Nonstocked Areas*

We set aside the areas of all sapling-seedling stands and nonstocked areas in a separate operability class (IV), inoperable. It is our opinion that little of this land would be harvested in the short term (although it might be managed for regeneration or release) and that including this land in operability estimates would dilute or negate the usefulness of operability data. Tables found in the Appendix show

class IV areas and volumes in order that totals would add to the State totals published after the 1977 inventory[4].

4. *Review of Process by Lake States Foresters*

We asked a sample of foresters from forest industry, State Departments of Natural Resources, universities, and public forest research agencies in the Lake States to review our operability class components and their values. Suggested changes were incorporated into the final components and factors used in this paper. The final operability class components and the three subclasses of each are shown in table 1.

5. *Develop Computer Program to Scan Inventory Records and Expand Plot Data*

We devised a computer program to search the FIA data base and (1) retrieve the values for each of the seven operability class components on every sample plot (except those in sapling-seedling stands or on nonstocked areas), and (2) assign an overall operability class rating (I, II, or III) to the plot. In order for a plot to receive an overall operability class I (Good) rating, *all* of the values for the seven components on the plot had to be class I. A plot was rated operability class II (Medium) if values for the seven components on the plot were either class I or II. A plot was rated operability class III (Poor) if *any* of the component values were class III. (E.g. if the values for six components on a plot were class I and the value for the remaining component was class III, the plot was considered operability class III.)

We used expansion factors developed during the 1977 State inventory to convert plot data to estimates of timberland area by operability class for Minnesota. We computed the volume by species for each plot and then expanded the data to an estimate of volume by operability class for the State.

[4]*Appendix tables do not add exactly to 1977 published totals because of slight procedural changes in data processing used in computing operability information from the method used in 1977.*

Table 1.--Operability component values for each operability class

Operability component	Operability class		
	I (Good)	II (Medium)	III (Poor)
1. Stand area (in acres)	More than 60	10-60	Less than 10
2. Growing-stock volume per acre (in cubic feet)	More than 800	300-800	Less than 300
3. Sawtimber volume per acre (in board feet 1/)	More than 3,000	1,100-3,000	Less than 1,100
4. Percent of all live trees that are cull (in percent)	Less than 20	20-50	More than 50
5. Average diameter at breast height (d.b.h.) of growing-stock trees (in inches)	More than 10	6-10	Less than 6
6. Average merchantable height of growing-stock trees (in feet)	More than 28	16-28	Less than 16
7. Distance to a maintained road (in miles)	Less than 1/4	1/4 - 3/4	More than 3/4

1/ International 1/4-inch rule.

6. *Method for Eliminating Limiting Operability Class Components Not Considered Relevant by the User*

Some operability class components might not be considered important by some users. To permit these users to develop operability classes containing only components of concern to them, we developed tables showing area of timberland in operability classes II and III by limiting factor (tables 8 and 9 in Appendix). Similar tables for growing-stock volume were also developed (tables 16 and 17).

A limiting factor represents the operability class component or components that prevent the indicated area or volume from being classed in a higher operability class. As mentioned earlier, a plot was rated operability class II if all values for the seven operability class components on the plot were either class I or II. The limiting factor tables for class II show the individual components that were rated class II and, therefore, caused the indicated area or volume to be rated class II rather than class I. Limiting factor tables for class III show the same information. The limiting factor tables, then, can be used to find the area or volume on plots called operability class II or III because of a component(s) considered unimportant by the reader, and this can be added to the area or volume listed as operability class I or II to produce a revised estimate.

For example, table 8 shows that limiting factor 1 (stand area—first of the seven operability class components) is responsible for 52,700 acres of timberland being placed in operability class II rather than class I. All other components in the plots represented by the 52,700 acres were rated operability class I. If you feel that stand area is not relevant to your needs, you can add the 52,700 acres to the 52,100 acres classed as operability class I in table 7 (fig. 2a). The resulting 104,800 acres is the adjusted area in operability class I if the constraint of stand area as an operability class component is removed. To estimate the growing-stock volume on the above 52,700 acres, table 16 shows that limiting factor 1 represents 90,453,000 cubic feet. Adding this to the 71,893,000 cubic feet of growing stock in table 15 estimated to be operability class I results in an adjusted class I volume of 162,346,000 cubic feet (fig. 2b). The limiting factor tables provide the information necessary to adjust areas and volumes for any combination of up to three operability class components.

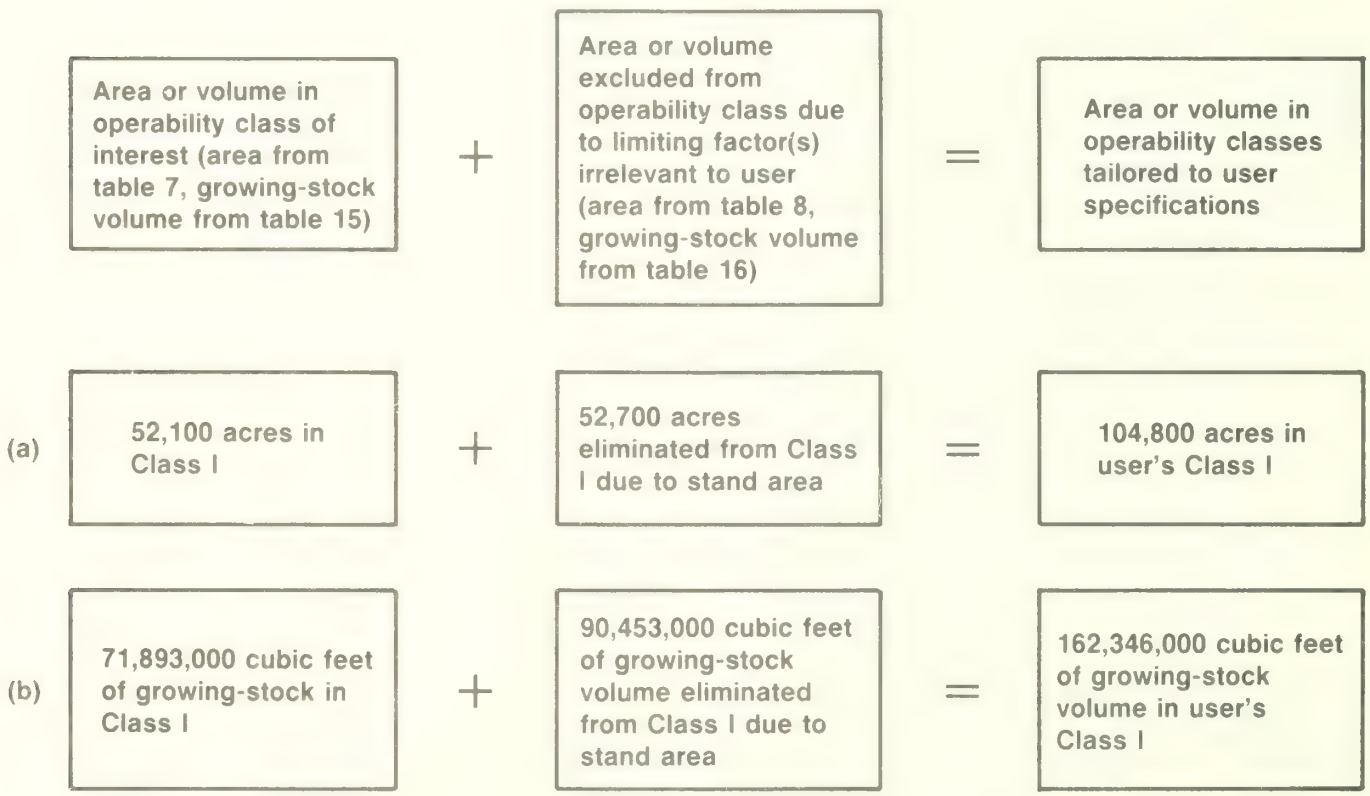
Area or volume in operability class of interest (area from table 7, growing-stock volume from table 15)
+
Area or volume excluded from operability class due to limiting factor(s) irrelevant to user (area from table 8, growing-stock volume from table 16)
=
Area or volume in operability classes tailored to user specifications
(a)
52,100 acres in Class I
+
52,700 acres eliminated from Class I due to stand area
=
104,800 acres in user's Class I
(b)
71,893,000 cubic feet of growing-stock in Class I
+
90,453,000 cubic feet of growing-stock volume eliminated from Class I due to stand area
=
162,346,000 cubic feet of growing-stock volume in user's Class I

Figure 2.—*Eliminating limiting operability class components not considered relevant by the user.*

7. *Estimate the Area of Timberland and the Volume of Growing Stock by Operability Class and by its Distance from the Major Wood-using Centers in the State*

During the aerial photo interpretation phase of the Minnesota forest inventory, the legal description of each plot (township, range, section, and quarter-quarter section) was recorded. Each plot legal description was then converted to Universal Transverse Mercator (UTM) coordinates, accurate to within 300 meters. (See Appendix for further discussion of Universal Transverse Mercator Grid System.)

We identified nine current major wood-using centers in Minnesota: Bemidji, Brainerd, Cloquet, Cook, Grand Rapids, International Falls, Sartell, the Twin Cities (Minneapolis-St. Paul), and Winona. The UTM coordinates for each of these cities were referenced and compared with the coordinates for each plot to get the straight-line distance between points. The area and volume associated with each plot could then be estimated in relation to its straight-line distance from each city. These plot areas and volumes were summed and stratified by operability class to produce an estimate of the area of timberland (table 13) and volume of growing stock (table 21) by distance from each of the nine wood-using centers and by operability class. Distances were grouped in three classes: (1) less than 20 miles, (2) from 20 to 50 miles, and (3) more than 50 miles.

DISCUSSION

The method described here is one of many possible avenues to evaluate operability. We acknowledge that factors other than the seven we selected to determine operability are important. However, our intent in this paper is to present a method based only on measurable, physical stand data that can be used by foresters and others without experience in forest economics. The necessary data are routinely collected in the North Central Region on FIA permanent sample plots used to inventory a State's timber resource and are readily available to the public through a data base management system[5]. Thus, users with programming ability can access the appropriate data base and write their own programs to assess operability.

[5]*Hahn, Jerold T.; Hansen, Mark H. Data bases for forest inventory in the North-Central Region. Gen. Tech. Rep. NC-101. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1985. 57 p.*

The method of assigning plot operability class used in this study may be considered too restrictive by some users. Analysts may wish to consider less stringent requirements in future studies. For example, a plot could be assigned operability class I if all values for the components were rated as I or II, but there were no more than 2 II's. A plot might be rated class II if component values were rated I, II, or III, but there were no more than 2 I's and 2 III's. Similarly, a plot might be rated class III if component values were rated II or III, but there were no more than 2 II's.

This method may serve users' needs as well as the original method, because it is not usually true that one low rating for a component should determine plot operability. In some cases, however, one component may decide operability class for a plot. For example, Minnesota Department of Natural Resources (DNR) foresters find that timber operators will usually bid on DNR saw log timber sales containing less than 1,000 board feet per acre if the stand contains large-diameter trees and/or high quality species. However, they may not bid on sales with the same volume per acre in small-diameter trees and/or low values species. Aspen pulpwood timber sales on DNR land are usually considered inoperable (economically infeasible) if they contain less than 5 cords per acre. In these cases, the volume per acre components could automatically trigger the plot to be assigned to the lowest operability class.

The described method weights the better operability classes toward stands with large trees and attendant large volumes per acre, such as many of those found in the oak-hickory and maple-basswood forest types. This is largely the result of the operability components selected by foresters to describe operability. Such stands are most likely to be harvested, particularly for saw logs. Forest types with typically small trees such as aspen-birch, black spruce, and jack pine are at a disadvantage in the method described.

We recognize that straight-line distance from the resource to a major wood-using center is not as useful a measure of economic feasibility as hauling (road) distance. Methods are available to calculate the hauling distance between two points; however, it was beyond the scope of this study to make these calculations. Future analysts of operability in other States may want to consider substituting hauling distance for straight-line distance.

The component values used here are appropriate for the Lake States in general and Minnesota in particular. When determining operability for other

States, the use of the same component values would facilitate comparisons across regions; however, values would undoubtedly be altered in other States to reflect local conditions and practices.

RESULTS FOR MINNESOTA

Area

Using the method outlined above, 7.1 million acres (52 percent of the total) of timberland in Minnesota are rated operability class III—Poor (table 7). Another 2.9 million acres (21 percent) are rated class II—Medium, and only 52,100 acres (less than 1 percent) are rated class I—Good. Class IV forest, sapling-seedling stands and nonstocked areas, total 3.6 million acres (27 percent).

Of the 15 forest types identified in Minnesota, only 5 have any area in operability class I (table 7). Of the 5, the oak-hickory type contains the greatest portion of its total area in class I—3 percent.

Adjustment by Limiting Factors

Using the method of limiting factors described earlier, forest areas can be shifted towards the good operability class (class I). For example, the 52,100 acres originally rated operability class I can be increased to 131,600 acres (52,100 + 79,500 acres from tables 7 and 8), if the single operability component of average d.b.h. of growing-stock trees is waived. Or, the total area in class I can be increased to 127,000 acres (52,100 + 74,900 acres) if the constraint on distance to road is removed. If both components are waived the new class I area becomes 406,700 acres (52,100 + 79,500 + 74,900 + 200,200 acres). Although the resulting 406,700 acres is 8 times larger than the original class I area, it still represents only 4 percent of the total of classes I-III in the State. This suggests, too, that the physical standards for some operability components may be too confining or that the definitions of operability classes could be modified. Those investigating operability in subsequent studies may wish to relax the standards somewhat to provide a different distribution of area among the three operability classes. However, new standards should reflect actual conditions and should not be developed only to achieve a more equal distribution of the resource among operability classes.

Likewise, the areas of class II and III forest can be adjusted. If the above two components (average d.b.h. of growing-stock trees and distance to road) are waived, the area of class II forest land changes from 2,935,000 to 3,265,900 acres. The adjusted area represents 32 percent of the class I-III total, an increase of 3 percent over the unadjusted area. This change causes the class III area to be adjusted from 7,073,800 to 6,388,300 acres. The new class III area is 64 percent of the three-class total instead of the original 70 percent.

Areas for individual forest types can likewise be adjusted. The 24,500 acres in the oak-hickory type rated operability class I (table 7) swells to 124,200 acres if limiting factors five and seven are applied (table 8). And the area of the aspen type in class I jumps from 1,400 to 108,100 acres after the same adjustment.

Volume Per Acre

As expected, higher volumes per acre are associated with the better operability classes (table 2). Although all the areas in class I have more than 800 cubic feet per acre, only 54 percent of class III land has the same volumes.

Table 2.--Timberland (excluding sapling-seedling stands and nonstocked areas) by growing-stock volume per acre class and operability class, Minnesota, 1977

(In percent)

Growing-stock volume per acre (cu.ft./acre)	Operability class		
	I	II	III
More than 800	100	82	54
300-800	--	18	41
Less than 300	--	--	5
Total	100	100	100

Ownership

The portion of timberland in each operability class differs substantially among ownership classes. Farmer-owned timberland, the owner class with the largest area in Minnesota, contains the highest portion of operability classes I and II and the smallest portion of operability class III. Generally, farmer-owned timberland is accessible by road in Minnesota and receives less forest management than timberland owned by some other parties. The latter may result in stands with greater volume per acre than stands owned by other groups, thus predisposing them to higher operability ratings.

National Forests, miscellaneous private parties, and Indian owners follow with the next highest portions in operability classes I and II (table 3).

Distance from Wood-using Center

Ignoring operability and sapling-seedling stands and nonstocked areas (operability class IV), a larger area of timberland (385,000 acres) is less than 20 miles (straight-line distance) from Bemidji, Minnesota, than from any of the other eight major wood-using centers in the State. Cook, Minnesota (377,000), and Grand Rapids, Minnesota (374,000), follow. If the timbershed is extended to a radius of from 20 to 50 miles, Grand Rapids is first (1,842,000 acres), followed by Bemidji (1,630,000) and Cook (1,626,000).

If, however, operability is factored into the consideration of distance of timberland from wood-using center, a clearer picture emerges. Winona, Minnesota, leads other cities in area of operability class I timberland less than 20 miles from town with 6,000 acres. However, because this is such a small area, as is the entire class I area, it makes more sense to discuss operability classes I and II combined here.

Bemidji leads all other centers less than 20 miles from operability class I and II timberland (154,000 acres), followed by Brainerd (125,000) and Grand Rapids (114,000). Therefore, although Cook is second in area of all operability classes of timberland within 20 miles of town (above), Brainerd is second in area of class I and II timberland located within this distance from town. Bemidji and Grand Rapids remain first and third, respectively, in the same comparison. Analysts, then, can use table 13 to estimate the difficulty of managing or harvesting timber from three different radii from nine different wood-using centers in the State.

Volume

Growing-stock volume on timberland in Minnesota was stratified into operability classes, just as was the area of timberland. Because the same kind of tables were generated for volume that were discussed for area above, only the highlights are discussed.

Table 3.--Timberland (excluding sapling-seedling stands and nonstocked areas) by ownership class and operability class, Minnesota, 1977

(In percent)

Ownership class	Operability class		
	I	II	III
Farmer	1	39	60
National Forest	1	35	64
Miscellaneous private	1	30	69
Indian	1	26	73
Other federal	--	23	77
County and municipal	--	22	78
Forest industry	--	22	78
State	--	19	81
All owners	1	29	70

Minnesota's 1977 operability class I-III growing-stock inventory of 10.5 billion cubic feet is broken down into operability classes as follows:

Operability class	Growing-stock inventory	
	(Million cubic feet)	(Percent)
I	72	1
II	3,743	35
III	6,723	64
All classes	10,538	100

The aspen type, which represents 41 percent of the combined volumes in classes I-III, represents only 4 percent of the operability class I volume (table 15). This again reflects the bias of the operability components selected towards larger, older trees.

Adjustment by Limiting Factors

Volumes can be adjusted to suit the needs of the user the same way area can be adjusted, as discussed earlier. If the same two operability components are waived as were used earlier in the area discussion (average d.b.h. of growing-stock trees and distance to road), the volume in operability class I changes from 72 to 672 million cubic feet (tables 15 and 16). Likewise, the volume in operability class II shifts from 3,743 to 4,057 million cubic feet and that in class III declines from 6,723 to 5,809 million cubic feet (tables 15 and 17). Percents in each class then become:

Operability class	Percent
I	6
II	39
III	55
All classes	100

Volume Per Acre

Average volume per acre differed somewhat by operability class and volume per acre class, but it generally is highest in the best operability classes (table 4). The extremely small volume in operability class I probably prevented the average volume per acre in that class from being greater than it is.

Ownership

The largest portion of growing-stock volume—like area, discussed earlier—in operability classes I and II is on farmer-owned timberland (table 5).

Distance from Wood-using Center

Bemidji is within 20 miles of 216 million cubic feet of operability class I and II growing stock—more than any other wood-using center in the State. Grand Rapids and Brainerd follow with 171 and 151 million cubic feet, respectively (table 21). The same cities are in the same order if the radius is extended to 50 miles.

Table 4.--Average growing-stock volume[1/] per acre on timberland by volume per acre class and operability class, Minnesota, 1977

(In cubic feet)

Cubic foot volume per acre class	Average all classes	Operability class I	II	III
More than 800	1,343	1,380	1,416	1,297
300-800	591	--	646	581
Less than 300	215	--	--	215

1/ Excludes growing-stock volume in sapling-seedling stands and on nonstocked areas.

Summary

The tables discussed above permit a user to separate timberland and the growing-stock volume on the land into operability classes and to do so by forest type, volume per acre class, stand-age class, ownership class, and distance from wood-using center. In addition, tables are provided that permit a user to discount up to three operability components and then determine operability class based on the remaining relevant components.

Table 5.--Growing-stock volume[1/] by ownership class and operability class, Minnesota, 1977

(In percent)

Ownership class	Operability class		
	I	II	III
Farmer	2	46	52
National Forest	1	43	56
Miscellaneous private	1	37	62
Indian	2/	34	66
Forest industry	--	28	72
County and municipal	--	27	73
Other federal	--	27	73
State	2/	24	76
All owners	1	35	64

1/ Excludes growing-stock volume in sapling-seedling stands and on nonstocked areas.
2/ Less than 0.5 percent.

APPENDIX

PRINCIPAL TREE SPECIES GROUPS IN MINNESOTA[6]

Softwoods
- Eastern white pine ..... *Pinus strobus*
- Red pine ..... *Pinus resinosa*
- Jack pine ..... *Pinus banksiana*
- Black spruce ..... *Picea mariana*
- White spruce ..... *Picea glauca*
- Balsam fir ..... *Abies balsamea*
- Tamarack ..... *Larix laricina*
- Northern white-cedar ..... *Thuja occidentalis*
- Other softwoods
  - Eastern redcedar ..... *Juniperus virginiana*
  - Scotch pine ..... *Pinus sylvestris*

Hardwoods
- White oaks
  - White oak ..... *Quercus alba*
  - Bur oak ..... *Quercus macrocarpa*
  - Swamp white oak ..... *Quercus bicolor*
- Select red oak
  - Northern red oak ..... *Quercus rubra*
- Other red oaks
  - Black oak ..... *Quercus velutina*
  - Northern pin oak ..... *Quercus ellipsoidalis*
- Hickories
  - Shagbark hickory ..... *Carya ovata*
  - Bitternut hickory ..... *Carya cordiformis*
- Yellow birch ..... *Betula alleghaniensis*
- Hard maples
  - Sugar maple ..... *Acer saccharum*
  - Black maple ..... *Acer nigrum*
- Soft maples
  - Red maple ..... *Acer rubrum*
  - Silver maple ..... *Acer saccharinum*
- Ashes
  - White ash ..... *Fraxinus americana*
  - Black ash ..... *Fraxinus nigra*
  - Green ash ..... *Fraxinus pennsylvanica*
- Balsam poplar ..... *Populus balsamifera*
- Paper birch ..... *Betula papyrifera*
- Aspens
  - Bigtooth aspen ..... *Populus grandidentata*
  - Quaking aspen ..... *Populus tremuloides*
- Basswood ..... *Tilia americana*
- Elms
  - American elm ..... *Ulmus americana*
  - Slippery elm ..... *Ulmus rubra*
  - Rock elm ..... *Ulmus thomasii*
- Select hardwoods
  - Butternut ..... *Juglans cinerea*
  - Black walnut ..... *Juglans nigra*
  - Black cherry ..... *Prunus serotina*
- Other hardwoods
  - Boxelder ..... *Acer negundo*
  - River birch ..... *Betula nigra*
  - Hackberry ..... *Celtis occidentalis*
  - Eastern cottonwood ..... *Populus deltoides*
  - Black willow ..... *Salix nigra*
  - Kentucky coffeetree ... *Gymnocladus dioicus*

[6]*The common and scientific names are based on: Little, Elbert D. Checklist of native and naturalized trees of the United States. Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service; 1979. 375 p.*

METRIC EQUIVALENTS OF UNITS USED IN THIS REPORT

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.

UNIVERSAL TRANSVERSE MERCATOR (UTM) GRID SYSTEM

The UTM Grid system is designed for world use between 80° south latitude and 84° north latitude. The globe is divided into narrow zones of 6° of longitude in width, numbered 1 through 60. Each zone is bounded on the east and west by a meridian of longitude and with a central meridian passing through the center of the grid zone. In the northern hemisphere the intersection of the central meridian and the equator is given a value of 0 meters for north-south coordinates, and the numbers increase towards the north pole. Because values increase from west to east, this same point of intersection is given a value of 500,000 meters for east-west coordinates to avoid negative numbers at the west edge of the zone. A grid system of two sets of parallel lines intersecting at right angles and forming a series of squares is established within each grid zone. On the U.S. Geological Survey maps used, the grid interval or length of each side of these squares is 1,000 meters. Each grid square can be referenced by two nu-

merical coordinates intersecting in the lower left corner of the square. The first of these coordinates represents the distance in meters east or west of the central meridian of the grid zone and the second coordinate represents the distance in meters north of the equator. Any point within a grid square can be referenced by using these coordinates and by dividing the sides of the grid square into 10 or multiples of 10 parts. The point coordinates, then, are read to a greater number of digits than the grid coordinates. Such a system permits location of a point to the nearest 10 meters.

DEFINITION OF TERMS

Commercial species.—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

County and municipal land.—Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

Diameter classes.—A classification of trees based on diameter outside bark, measured at breast height (4½ feet above the ground). (Note: d.b.h. is the common abbreviation for diameter at breast height. Two-inch diameter classes are commonly used in Forest Inventory and Analysis, with the even inch the approximate midpoint for a class. For example, the 6-inch class includes trees 5.0 through 6.9 inches d.b.h.)

Farm.—Any place from which $1,000 or more of agricultural products were produced and sold during the year.

Farmer-owned land.—Land owned by farm operators. (Note: Excludes land leased by farm operators from nonfarm owners, such as railroad companies and States.)

Forest land.—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note: Stocking is measured by comparing specified standards with basal area and/or number of trees, age or size, and spacing.) The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas are classed as forest if less than 120 feet wide. Also see definitions for land area, timberland, unproductive forest land, and water.

Forest industry land.—Land owned by companies or individuals operating primary wood-using plants.

Forest trees.—Woody plants having a well-developed stem and usually more than 12 feet tall at maturity.

Forest type.—A classification of forest land based on the species forming a plurality of live tree stocking. Major forest types in the State are:

Jack pine.—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

Red pine.—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

White pine.—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, aspen, birch, and maple.)

Balsam fir.—Forests in which balsam fir and white spruce comprise a plurality of the stocking with balsam fir the most common. (Common associates include white spruce, aspen, maple, birch, northern white-cedar, and tamarack.)

White spruce.—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include balsam fir, aspen, maple, birch, and northern white-cedar.)

Black spruce.—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

Northern white-cedar.—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

Tamarack.—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

Oak-hickory.—Forests in which northern red oak, white oak, or bur oak, singly or in combination, comprise a plurality of the stocking. (Common associates include aspen, elm, and maple.)

Elm-ash-cottonwood.—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include basswood and balsam poplar.)

Maple-basswood.—Forests in which sugar maple, basswood, yellow birch, elm, and red

maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine and elm.)

Aspen.—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

Paper birch.—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

Balsam poplar.—Forests in which balsam poplar comprises a plurality of the stocking. (Common associates include aspen, elm, and ash.)

Growing-stock trees.—Live trees of commercial species qualifying as desirable and acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Growing-stock volume.—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to standard cords by dividing by 79. One standard cord is 128 cubic feet of stacked wood, including bark and air.

Hardwoods.—Dicotyledonous trees, usually broad-leaved and deciduous.

Indian land.—All lands held in trust by the United States for individual Indians or tribes, or all lands, titles to which are held by indiviual Indians or tribes, subject to Federal restrictions against alienation.

Land area.—A. *Bureau of the Census*. The area of dry land and land temporarily or partly covered by water such as marshes, swamps, and river flood plains (omitting tidal flats below mean high tide); streams, sloughs, estuaries, and canals less than one-eighth of a statute mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

B. *Forest Inventory and Analysis*. The same as the Bureau of the Census, except minimum width of streams, etc., is 120 feet and minimum size of lakes, etc., is 1 acre.

Live trees.—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

Maintained road.—Any road, hard-topped or other surface, that is plowed or graded at least once a year. Includes rights-of-way that are cut or treated to limit herbaceous growth.

Miscellaneous Federal land.—Federal land other than National Forest and land administered by the Bureau of Land Management.

Miscellaneous private land.—Privately owned land other than forest-industry and farmer-owned land.

Mortality.—The volume of sound wood in growing-stock and sawtimber trees that die annually.

National Forest land.—Federal land that has been legally designated as National Forest or purchase units, and other land administered by the USDA Forest Service.

Net volume.—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

Noncommercial species.—Tree species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial wood products.

Nonforest land.—Land that has never supported forests, and land formerly forested where use for timber management is precluded by development for other uses. (Note: Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 40-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide and more than 1 acre in area to qualify as nonforest land.)

a. *Nonforest land without trees*.—Nonforest land with no live trees present.

b. *Nonforest land with trees*.—Nonforest land with one or more trees per acre at least 5 inches d.b.h.

Nonstocked land.—Timberland less than 16.7 percent stocked with growing-stock trees.

Poletimber trees.—Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber size.

Saplings.—Live trees 1 to 5 inches d.b.h.

Sapling-seedling stands.—(See stand-size class.)

Saw log.—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) of 7 inches for softwoods (9 inches for hardwoods) or other combinations of size and defect specified by regional standards.

Saw log portion.—That part of the bole of sawtimber trees between the stump and the saw log top.

Saw log top.—The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for softwoods and 9 inches d.o.b. for hardwoods.

Sawtimber stands.—(See stand-size class.)

Sawtimber trees.—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting regional specifications for freedom

from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

Sawtimber volume.—Net volume of the saw log portion of live sawtimber in board feet, International 1/4-inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

Seedlings.—Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

Softwoods.—Coniferous trees, usually evergreen, having needles or scale-like leaves.

Stand.—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

Stand-age class.—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

Stand-size class.—A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber, or seedlings and saplings.

a. *Sawtimber stands*.—Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

b. *Poletimber stands*.—Stands at least 16.7 percent stocked with growing-stock trees of which half or more of this stocking is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

c. *Sapling-seedling stands*.—Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the stocking is saplings and/or seedlings.

d. *Nonstocked areas*.—Timberland on which stocking of growing-stock trees is less than 16.7 percent.

State land.—Land either owned by States or leased to them for 50 years or more.

Timberland.—Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of annual growth when managed. Currently inaccessible and inoperable areas are included except when the areas involved are small and unlikely to become suitable for producing industrial wood in the foreseeable future.)

Unproductive forest land.—Forest land incapable of producing 20 cubic feet per acre of annual growth or of yielding crops of industrial wood under natural conditions because of adverse site conditions. (Note: Adverse conditions include shallow soil, dry climate, poor drainage, high elevation, steepness, and rockiness.)

Upper stem portion.—That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4 inches outside bark or to the point where the central stem breaks into limbs.

Urban and other areas.—Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; powerlines; other rights-of-way; or other nonforest land not included in any other specified land use class.

Water—(a) *Bureau of the Census*.—Permanent inland water surfaces, such as lakes, reservoirs, and ponds at least 40 acres in area; and streams, sloughs, estuaries, and canals at least one-eighth of a statute mile wide.

(b) *Noncensus*.—Permanent inland water surfaces, such as lakes, reservoirs, and ponds from 1 to 39.9 acres in area; and streams, sloughs, estuaries, and canals from 120 feet to one-eighth of a statute mile wide.

TABLES

Text Tables

Table 1.— Operability component values for each operability class

Table 2.— Timberland (excluding sapling-seedling stands and nonstocked areas) by growing-stock volume per acre class and operability class

Table 3.— Timberland (excluding sapling-seedling stands and nonstocked areas) by ownership class and operability class

Table 4.— Average growing-stock volume per acre on timberland by volume per acre class and operability class

Table 5.—Growing-stock volume by ownership class and operability class

Appendix Tables

Table 6.— Area of timberland by operability class component and forest type

Table 7.—Area of timberland by forest type and operability class

Table 8.—Area of timberland in operability class II (medium) by limiting factor and forest type

Table 9.—Area of timberland in operability class III (poor) by limiting factor and forest type
Table 10.—Area of timberland by forest type, average growing-stock volume per acre and operability class
Table 11.—Area of timberland by forest type, stand-age class, and operability class
Table 12.—Area of timberland by forest type, ownership class, and operability class
Table 13.—Area of timberland by distance from major wood-using center and operability class
Table 14.—Growing-stock volume on timberland by operability class component and forest type
Table 15.—Growing-stock volume on timberland by forest type and operability class
Table 16.—Growing-stock volume on timberland in operability class II (medium) by limiting factor and forest type
Table 17.—Growing-stock volume on timberland in operability class III (poor) by limiting factor and forest type
Table 18.—Growing-stock volume on timberland by forest type, average growing-stock volume per acre and operability class
Table 19.—Growing-stock volume on timberland by forest type, stand-age class, and operability class
Table 20.—Growing-stock volume on timberland by forest type, ownership class, and operability class.
Table 21.—Growing-stock volume on timberland by distance from major wood-using center and operability class

Table 6.--Area of timberland by operability class component and forest type, Minnesota, 1977

(In thousand acres)

Operability class component	All types	Forest type: Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
Stand area (acres)									
More than 60	3,176.9	88.8	29.3	15.6	85.9	20.7	207.4	59.8	75.1
10-60	4,391.6	139.3	136.6	13.9	230.2	12.9	306.9	140.3	151.9
Less than 10	6,135.4	276.3	81.1	36.1	541.5	45.6	527.7	298.5	238.9
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Growing-stock volume per acre (cubic feet/acre)									
More than 800	6,370.3	294.8	183.4	59.5	384.0	20.7	221.4	212.6	81.1
300-800	4,581.7	170.3	35.5	4.2	335.8	26.4	352.2	189.7	181.0
Less than 300	2,751.9	39.3	28.1	1.9	137.8	32.1	468.4	96.3	203.8
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Sawtimber volume per acre (board feet/acre)									
More than 3000	2,719.1	140.6	156.5	57.0	125.4	15.3	20.2	115.0	13.9
1100-3000	3,875.5	160.5	31.8	6.7	296.6	15.5	118.4	164.8	77.0
Less than 1100	7,109.3	203.3	58.7	1.9	435.6	48.4	903.4	218.8	375.0
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Percent cull trees (percent)									
Less than 20	8,386.1	439.6	181.0	49.2	630.0	37.3	794.1	253.0	301.4
20-50	3,957.4	50.0	46.0	13.2	179.4	17.3	115.7	205.5	95.9
More than 50	1,360.4	14.8	20.0	3.2	48.2	24.6	132.2	40.1	68.6
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Average d.b.h. of growing-stock trees (inches)									
More than 10	1,581.6	30.8	50.3	13.3	35.4	6.9	10.0	18.0	12.4
6-10	10,764.5	423.5	170.5	50.4	783.4	48.4	655.4	445.8	314.3
Less than 6	1,357.8	50.1	26.2	1.9	38.8	23.9	376.6	34.8	139.2
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Average merchantable height of growing-stock trees (feet)									
More than 28	8,543.7	249.1	172.8	54.4	374.9	28.9	230.1	65.5	118.8
16-28	4,469.6	236.3	55.6	9.3	470.0	29.8	691.6	408.1	292.6
Less than 16	690.6	19.0	18.6	1.9	12.7	20.5	120.3	25.0	54.5
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9
Distance to road (miles)									
Less than 1/4	4,690.3	270.6	111.1	21.1	201.0	38.0	163.7	92.0	102.6
1/4 - 3/4	6,173.2	195.4	106.8	38.7	404.6	16.1	430.8	198.6	187.7
More than 3/4	2,840.4	38.4	29.1	5.8	252.0	25.1	447.5	208.0	175.6
All classes	13,703.9	504.4	247.0	65.6	857.6	79.2	1,042.0	498.6	465.9

(Table 6 continued on the next page)

(Table 6 continued)

Operability class component	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
Stand area (acres)							
More than 60	438.6	106.1	378.7	1,329.1	288.7	45.4	7.7
10-60	262.6	210.3	491.8	1,753.9	348.6	158.0	34.4
Less than 10	196.3	421.8	415.3	2,222.1	361.4	345.2	127.6
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Growing-stock volume per acre (cubic feet/acre)							
More than 800	464.7	314.7	731.3	2,610.5	587.8	203.8	--
300-800	345.0	302.4	433.1	1,694.8	310.3	192.2	8.8
Less than 300	87.8	121.1	121.4	999.8	100.6	152.6	160.9
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Sawtimber volume per acre (board feet/acre)							
More than 3000	364.2	151.5	578.5	770.8	125.1	85.1	--
1100-3000	308.3	266.6	397.8	1,519.4	373.9	135.4	2.8
Less than 1100	225.0	320.1	309.5	3,014.9	499.7	328.1	166.9
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Percent cull trees (percent)							
Less than 20	537.1	427.2	632.6	3,005.8	702.7	343.5	51.6
20-50	286.9	253.4	518.3	1,762.4	247.1	150.4	15.9
More than 50	73.5	57.6	134.9	536.9	48.9	54.7	102.2
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Average d.b.h. of growing-stock trees (inches)							
More than 10	338.1	84.1	425.8	428.7	54.5	50.6	22.7
6-10	546.1	633.1	846.8	4,442.9	892.9	431.6	79.4
Less than 6	13.3	21.0	13.2	433.5	51.3	66.4	67.6
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Average merchantable height of growing-stock trees (feet)							
More than 28	718.1	464.4	1,088.0	3,892.4	704.5	340.7	41.1
16-28	167.6	263.1	194.8	1,149.8	269.1	170.0	61.9
Less than 16	11.8	10.7	3.0	262.9	25.1	37.9	66.7
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7
Distance to road (miles)							
Less than 1/4	407.1	257.5	532.9	1,938.2	296.4	215.2	42.9
1/4 - 3/4	456.3	353.1	584.7	2,422.8	444.8	251.0	81.8
More than 3/4	34.1	127.6	168.2	944.1	257.5	82.4	45.0
All classes	897.5	738.2	1,285.8	5,305.1	998.7	548.6	169.7

Table 7.--Area of timberland by forest type and operability class, Minnesota, 1977

(In thousand acres)

Forest type	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack pine	504.4	2.4	126.1	294.6	81.3
Red pine	247.0	--	60.2	103.5	83.3
White pine	65.6	--	24.9	37.4	3.3
Balsam fir	857.6	--	119.6	510.8	227.2
White spruce	79.2	--	3.6	37.7	37.9
Black spruce	1,042.0	--	36.3	404.7	601.0
Northern white-cedar	498.6	--	51.5	372.4	74.7
Tamarack	465.9	--	25.1	216.4	224.4
Oak-hickory	897.5	24.5	460.0	332.7	80.3
Elm-ash-cottonwood	738.2	1.4	145.9	435.2	155.7
Maple-basswood	1,285.8	22.4	521.8	625.9	115.7
Aspen	5,305.1	1.4	1,065.4	2,731.0	1,507.3
Paper birch	998.7	--	219.1	682.7	96.9
Balsam poplar	548.6	--	75.5	288.8	184.3
Nonstocked	169.7	--	--	--	169.7
All types	13,703.9	52.1	2,935.0	7,073.8	3,643.0

Table 8.--Area of timberland in operability class II (medium) by limiting factor and forest type, Minnesota, 1977

(In thousand acres)

Limiting factor	All types	Forest type							
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1	52.7	--	5.9	1.4	--	--	--	--	--
2	6.5	--	0.4	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--
4	32.2	--	--	--	--	--	--	--	--
5	79.5	8.9	--	5.2	--	--	--	1.4	--
6	--	--	--	--	--	--	--	--	--
7	74.9	--	5.8	1.4	--	--	--	--	--
1 & 2	8.7	--	--	--	--	--	--	--	--
1 & 3	3.1	--	--	--	--	--	--	--	--
1 & 4	44.7	--	--	--	--	--	--	1.3	--
1 & 5	134.9	16.2	13.4	1.6	4.0	--	--	3.5	--
1 & 6	--	--	--	--	--	--	--	--	--
1 & 7	56.8	4.9	2.8	1.4	--	1.3	--	--	--
2 & 3	4.6	--	--	--	--	--	--	--	--
2 & 4	10.6	--	--	--	--	--	--	--	--
2 & 5	1.5	--	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--	--	--
2 & 7	15.0	1.7	--	--	--	--	--	--	1.6
3 & 4	5.4	--	--	--	--	--	--	--	--
3 & 5	83.6	2.8	1.4	--	--	--	--	--	--
3 & 6	--	--	--	--	--	--	--	--	--
3 & 7	--	--	--	--	--	--	--	--	--
4 & 5	26.3	--	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--	--	--
4 & 7	86.2	--	--	--	--	--	--	--	--
5 & 6	3.5	2.0	--	--	--	--	--	--	--
5 & 7	200.2	13.4	1.1	5.2	9.8	--	1.4	1.4	--
6 & 7	--	--	--	--	--	--	--	--	--

(Table 8 continued on the next page)

(Table 8 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1	11.1	--	24.6	8.3	--	1.4	--
2	4.6	--	1.5	--	--	--	--
3	--	--	--	--	--	--	--
4	9.9	2.6	19.7	--	--	--	--
5	19.2	1.3	11.2	26.8	2.7	2.8	--
6	--	--	--	--	--	--	--
7	39.9	4.2	17.6	6.0	--	--	--
1 & 2	1.5	--	5.8	1.4	--	--	--
1 & 3	--	--	1.6	1.5	--	--	--
1 & 4	17.1	1.3	14.4	9.3	1.3	--	--
1 & 5	14.7	6.9	24.8	38.0	9.0	2.8	--
1 & 6	--	--	--	--	--	--	--
1 & 7	10.9	1.4	22.2	7.8	2.7	1.4	--
2 & 3	1.7	--	1.5	1.4	--	--	--
2 & 4	9.0	--	1.6	--	--	--	--
2 & 5	1.5	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--
2 & 7	8.5	1.6	1.6	--	--	--	--
3 & 4	--	--	1.4	4.0	--	--	--
3 & 5	16.0	--	7.2	41.2	15.0	--	--
3 & 6	--	--	--	--	--	--	--
3 & 7	--	--	--	--	--	--	--
4 & 5	2.8	1.1	7.7	14.7	--	--	--
4 & 6	--	--	--	--	--	--	--
4 & 7	30.0	--	31.8	24.4	--	--	--
5 & 6	1.5	--	--	--	--	--	--
5 & 7	40.6	5.9	39.0	73.9	4.3	4.2	--
6 & 7	--	--	--	--	--	--	--

(Table 8 continued on the next page)

(Table 8 continued)

Limiting factor	Forest type								
	All types	Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1 & 2 & 3	17.3	--	--	--	1.6	--	--	--	--
1 & 2 & 4	2.8	--	--	--	--	--	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--	--	--
1 & 2 & 7	4.7	--	1.4	--	--	--	--	--	--
1 & 3 & 4	3.9	--	--	--	--	--	--	--	--
1 & 3 & 5	145.1	8.1	1.4	--	6.7	--	--	--	--
1 & 3 & 6	--	--	--	--	--	--	--	--	--
1 & 3 & 7	5.4	1.4	--	--	--	--	--	--	--
1 & 4 & 5	43.6	--	--	--	--	--	--	--	--
1 & 4 & 6	--	--	--	--	--	--	--	--	--
1 & 4 & 7	68.6	--	5.8	1.4	--	--	--	2.6	--
1 & 5 & 6	10.6	--	--	--	1.4	--	--	1.4	1.4
1 & 5 & 7	204.8	15.7	8.2	2.1	10.5	--	3.9	2.7	1.1
1 & 6 & 7	--	--	--	--	--	--	--	--	--
2 & 3 & 4	5.8	--	--	--	--	--	--	--	--
2 & 3 & 5	25.6	--	--	--	--	--	--	5.3	--
2 & 3 & 6	--	--	--	--	--	--	--	--	--
2 & 3 & 7	4.4	--	--	--	--	--	--	--	--
2 & 4 & 5	1.3	--	--	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--	--	--
2 & 4 & 7	9.4	--	--	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--	--	--
2 & 5 & 7	2.6	--	--	--	--	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--	--	--
3 & 4 & 5	39.6	--	--	--	8.5	--	--	--	--
3 & 4 & 6	--	--	--	--	--	--	--	--	--
3 & 4 & 7	4.0	--	--	--	--	--	--	--	--
3 & 5 & 6	9.5	3.9	--	--	--	--	--	--	--
3 & 5 & 7	226.5	7.8	--	--	11.0	--	1.4	--	1.3
3 & 6 & 7	--	--	--	--	--	--	--	--	--
4 & 5 & 6	1.6	--	--	--	--	--	--	--	--
4 & 5 & 7	49.9	--	--	--	--	--	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--	--	--
5 & 6 & 7	11.9	--	--	3.8	--	--	--	3.9	--
4 or more	1,105.2	39.3	12.6	1.4	66.1	2.3	29.6	28.0	19.7
All factors	2,935.0	126.1	60.2	24.9	119.6	3.6	36.3	51.5	25.1

(Table 8 continued on the next page)

(Table 8 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1 & 2 & 3	3.3	2.7	5.5	4.2	--	--	--
1 & 2 & 4	1.3	--	1.5	--	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--
1 & 2 & 7	--	--	3.3	--	--	--	--
1 & 3 & 4	--	--	1.1	2.8	--	--	--
1 & 3 & 5	10.2	9.9	12.8	70.2	16.4	9.4	--
1 & 3 & 6	--	--	--	--	--	--	--
1 & 3 & 7	--	--	--	4.0	--	--	--
1 & 4 & 5	2.5	3.3	6.8	24.4	4.0	2.6	--
1 & 4 & 6	--	--	--	--	--	--	--
1 & 4 & 7	8.7	2.5	22.8	20.4	1.3	3.1	--
1 & 5 & 6	--	--	5.0	1.4	--	--	--
1 & 5 & 7	9.8	11.2	31.7	80.6	17.7	9.6	--
1 & 6 & 7	--	--	--	--	--	--	--
2 & 3 & 4	4.5	--	1.3	--	--	--	--
2 & 3 & 5	7.8	1.6	1.4	9.5	--	--	--
2 & 3 & 6	--	--	--	--	--	--	--
2 & 3 & 7	1.7	--	1.3	1.4	--	--	--
2 & 4 & 5	1.3	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--
2 & 4 & 7	9.4	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--
2 & 5 & 7	--	1.3	1.3	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--
3 & 4 & 5	4.0	1.4	5.5	17.4	1.4	1.4	--
3 & 4 & 6	--	--	--	--	--	--	--
3 & 4 & 7	2.6	--	--	1.4	--	--	--
3 & 5 & 6	3.0	1.3	--	1.3	--	--	--
3 & 5 & 7	17.5	5.6	16.5	128.2	33.0	4.2	--
3 & 6 & 7	--	--	--	--	--	--	--
4 & 5 & 6	--	--	1.6	--	--	--	--
4 & 5 & 7	4.1	1.4	12.4	32.0	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--
5 & 6 & 7	--	--	4.2	--	--	--	--
4 or more	127.8	77.4	150.6	407.5	110.3	32.6	--
All factors	460.0	145.9	521.8	1,065.4	219.1	75.5	--

Table 9.--Area of timberland in operability class III (poor) by limiting factor and forest type, Minnesota, 1977

(In thousand acres)

Limiting factor	All types	Forest type							
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1	1,901.2	139.0	58.9	31.7	144.6	15.6	24.8	105.6	32.2
2	9.7	--	1.1	--	--	--	--	--	1.6
3	1,404.6	46.1	6.6	--	45.7	3.2	66.9	18.9	22.5
4	105.1	--	--	--	1.4	--	--	3.1	1.6
5	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--
7	685.5	6.9	20.0	2.7	39.2	5.6	31.7	42.0	14.3
1 & 2	10.0	--	--	--	--	--	--	1.2	--
1 & 3	1,118.1	73.1	2.4	--	113.6	7.4	79.4	33.4	36.1
1 & 4	81.3	--	1.4	1.3	--	--	--	3.9	--
1 & 5	--	--	--	--	--	--	--	--	--
1 & 6	--	--	--	--	--	--	--	--	--
1 & 7	449.0	15.0	7.7	1.7	72.8	3.9	32.9	64.1	11.9
2 & 3	86.6	--	--	--	2.5	--	2.9	6.7	2.8
2 & 4	3.8	--	--	--	--	--	--	--	--
2 & 5	--	--	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--	--	--
2 & 7	--	--	--	--	--	--	--	--	--
3 & 4	49.7	--	--	--	--	--	--	1.5	--
3 & 5	65.6	1.4	1.9	--	1.3	--	18.4	--	10.0
3 & 6	--	--	--	--	--	--	--	--	--
3 & 7	401.2	1.7	--	--	33.6	--	45.7	19.2	33.5
4 & 5	--	--	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--	--	--
4 & 7	19.9	--	--	--	1.5	0.7	--	3.0	--
5 & 6	--	--	--	--	--	--	--	--	--
5 & 7	--	--	--	--	--	--	--	--	--
6 & 7	--	--	--	--	--	--	--	--	--

(Table 9 continued on the next page)

(Table 9 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1	110.7	160.4	214.7	610.5	158.3	94.2	--
2	3.1	--	2.5	--	1.4	--	--
3	92.0	49.6	67.9	784.3	168.5	32.4	--
4	21.3	8.7	43.8	23.8	1.4	--	--
5	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--
7	15.2	40.1	72.4	299.2	82.2	14.0	--
1 & 2	2.2	1.6	2.5	2.5	--	--	--
1 & 3	26.2	82.6	62.9	443.7	80.7	76.6	--
1 & 4	17.0	10.8	23.1	19.4	1.4	3.0	--
1 & 5	--	--	--	--	--	--	--
1 & 6	--	--	--	--	--	--	--
1 & 7	1.4	33.0	32.2	127.1	27.8	17.5	--
2 & 3	13.7	11.8	16.9	17.9	7.1	4.3	--
2 & 4	0.7	--	3.1	--	--	--	--
2 & 5	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--
2 & 7	--	--	--	--	--	--	--
3 & 4	6.1	2.7	6.8	27.2	4.0	1.4	--
3 & 5	--	1.4	2.8	25.7	1.4	1.3	--
3 & 6	--	--	--	--	--	--	--
3 & 7	8.3	11.7	24.9	145.7	61.9	15.0	--
4 & 5	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--
4 & 7	--	--	7.8	5.5	--	1.4	--
5 & 6	--	--	--	--	--	--	--
5 & 7	--	--	--	--	--	--	--
6 & 7	--	--	--	--	--	--	--

(Table 9 continued on the next page)

(Table 9 continued)

Limiting factor	All types	Forest type: Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1 & 2 & 3	119.9	2.6	--	--	10.2	--	12.7	6.4	7.7
1 & 2 & 4	4.4	--	--	--	--	--	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--	--	--
1 & 2 & 7	2.3	--	--	--	--	--	--	1.1	1.2
1 & 3 & 4	21.5	--	--	--	--	--	1.1	--	--
1 & 3 & 5	27.7	1.4	2.1	--	1.1	--	6.3	1.6	3.6
1 & 3 & 6	1.6	--	--	--	--	--	--	1.6	--
1 & 3 & 7	270.1	1.5	1.4	--	32.4	1.3	46.1	19.8	17.0
1 & 4 & 5	--	--	--	--	--	--	--	--	--
1 & 4 & 6	--	--	--	--	--	--	--	--	--
1 & 4 & 7	20.9	1.3	--	--	1.3	--	1.3	2.2	--
1 & 5 & 6	--	--	--	--	--	--	--	--	--
1 & 5 & 7	--	--	--	--	--	--	--	--	--
1 & 6 & 7	--	--	--	--	--	--	--	--	--
2 & 3 & 4	22.9	--	--	--	2.7	--	--	--	--
2 & 3 & 5	3.0	--	--	--	--	--	1.3	--	--
2 & 3 & 6	--	--	--	--	--	--	--	--	--
2 & 3 & 7	22.7	--	--	--	1.4	--	3.8	1.3	4.3
2 & 4 & 5	--	--	--	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--	--	--
2 & 4 & 7	--	--	--	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--	--	--
2 & 5 & 7	--	--	--	--	--	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--	--	--
3 & 4 & 5	--	--	--	--	--	--	--	--	--
3 & 4 & 6	--	--	--	--	--	--	--	--	--
3 & 4 & 7	4.0	--	--	--	--	--	--	--	--
3 & 5 & 6	1.1	--	--	--	--	--	--	1.1	--
3 & 5 & 7	54.9	4.6	--	--	4.1	--	19.8	5.6	8.8
3 & 6 & 7	1.4	--	--	--	--	--	--	1.4	--
4 & 5 & 6	--	--	--	--	--	--	--	--	--
4 & 5 & 7	--	--	--	--	--	--	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--	--	--
5 & 6 & 7	--	--	--	--	--	--	--	--	--
4 or more	104.1	--	--	--	1.4	--	9.6	27.7	7.3
All factors	7,073.8	294.6	103.5	37.4	510.8	37.7	404.7	372.4	216.4

(Table 9 continued on the next page)

(Table 9 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1 & 2 & 3	7.5	6.8	12.3	33.5	7.3	12.9	--
1 & 2 & 4	--	1.4	1.3	1.7	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--
1 & 2 & 7	--	--	--	--	--	--	--
1 & 3 & 4	--	2.6	--	13.9	3.9	--	--
1 & 3 & 5	--	--	1.6	7.0	--	3.0	--
1 & 3 & 6	--	--	--	--	--	--	--
1 & 3 & 7	--	5.8	7.0	100.1	31.2	6.5	--
1 & 4 & 5	--	--	--	--	--	--	--
1 & 4 & 6	--	--	--	--	--	--	--
1 & 4 & 7	1.4	--	2.7	8.3	1.4	1.0	--
1 & 5 & 6	--	--	--	--	--	--	--
1 & 5 & 7	--	--	--	--	--	--	--
1 & 6 & 7	--	--	--	--	--	--	--
2 & 3 & 4	4.6	1.3	5.9	7.0	1.4	--	--
2 & 3 & 5	--	--	--	--	1.7	--	--
2 & 3 & 6	--	--	--	--	--	--	--
2 & 3 & 7	--	--	--	2.7	9.2	--	--
2 & 4 & 5	--	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--
2 & 4 & 7	--	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--
2 & 5 & 7	--	--	--	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--
3 & 4 & 5	--	--	--	--	--	--	--
3 & 4 & 6	--	--	--	--	--	--	--
3 & 4 & 7	1.3	--	--	2.7	--	--	--
3 & 5 & 6	--	--	--	--	--	--	--
3 & 5 & 7	--	--	--	1.4	9.2	1.4	--
3 & 6 & 7	--	--	--	--	--	--	--
4 & 5 & 6	--	--	--	--	--	--	--
4 & 5 & 7	--	--	--	--	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--
5 & 6 & 7	--	--	--	--	--	--	--
4 or more	--	2.9	10.8	20.2	21.3	2.9	--
All factors	332.7	435.2	625.9	2,731.0	682.7	288.8	--

Table 10.--Area of timberland by forest type, average growing-stock volume per acre, and operability class, Minnesota, 1977

(In thousand acres)

Forest type and average growing-stock volume per acre (cu.ft. per acre)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
More than 800	294.8	2.4	113.0	176.5	2.9
300-800	170.3	--	13.1	115.5	41.7
Less than 300	39.3	--	--	2.6	36.7
Total	504.4	2.4	126.1	294.6	81.3
Red pine					
More than 800	183.4	--	57.1	88.4	37.9
300-800	35.5	--	3.1	14.0	18.4
Less than 300	28.1	--	--	1.1	27.0
Total	247.0	--	60.2	103.5	83.3
White pine					
More than 800	59.5	--	24.9	34.6	--
300-800	4.2	--	--	2.8	1.4
Less than 300	1.9	--	--	--	1.9
Total	65.6	--	24.9	37.4	3.3
Balsam fir					
More than 800	384.0	--	95.7	285.3	3.0
300-800	335.8	--	23.9	208.7	103.2
Less than 300	137.8	--	--	16.8	121.0
Total	857.6	--	119.6	510.8	227.2
White spruce					
More than 800	20.7	--	2.9	17.8	--
300-800	26.4	--	0.7	19.9	5.8
Less than 300	32.1	--	--	--	32.1
Total	79.2	--	3.6	37.7	37.9
Black spruce					
More than 800	221.4	--	28.6	191.4	1.4
300-800	352.2	--	7.7	189.9	154.6
Less than 300	468.4	--	--	23.4	445.0
Total	1,042.0	--	36.3	404.7	601.0
Northern white-cedar					
More than 800	212.6	--	29.7	182.9	--
300-800	189.7	--	21.8	151.6	16.3
Less than 300	96.3	--	--	37.9	58.4
Total	498.6	--	51.5	372.4	74.7
Tamarack					
More than 800	81.1	--	13.6	67.5	--
300-800	181.0	--	11.5	124.0	45.5
Less than 300	203.8	--	--	24.9	178.9
Total	465.9	--	25.1	216.4	224.4

(Table 10 continued on the next page)

(Table 10 continued)

Forest type and average growing-stock volume per acre (cu.ft. per acre)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Oak-hickory					
More than 800	464.7	24.5	317.6	122.6	--
300-800	345.0	--	142.4	178.3	24.3
Less than 300	87.8	--	--	31.8	56.0
Total	897.5	24.5	460.0	332.7	80.3
Elm-ash-cottonwood					
More than 800	314.7	1.4	97.6	215.7	--
300-800	302.4	--	48.3	193.7	60.4
Less than 300	121.1	--	.0	25.8	95.3
Total	738.2	1.4	145.9	435.2	155.7
Maple-basswood					
More than 800	731.3	22.4	414.1	294.8	--
300-800	433.1	--	107.7	275.8	49.6
Less than 300	121.4	--	--	55.3	66.1
Total	1,285.8	22.4	521.8	625.9	115.7
Aspen					
More than 800	2,610.5	1.4	940.9	1,637.9	30.3
300-800	1,694.8	--	124.5	1,010.4	559.9
Less than 300	999.8	--	--	82.7	917.1
Total	5,305.1	1.4	1,065.4	2,731.0	1,507.3
Paper birch					
More than 800	587.8	--	194.2	388.8	4.8
300-800	310.3	--	24.9	244.5	40.9
Less than 300	100.6	--	--	49.4	51.2
Total	998.7	--	219.1	682.7	96.9
Balsam poplar					
More than 800	203.8	--	68.4	135.4	--
300-800	192.2	--	7.1	133.3	51.8
Less than 300	152.6	--	--	20.1	132.5
Total	548.6	--	75.5	288.8	184.3
Nonstocked					
More than 800	--	--	--	--	--
300-800	8.8	--	--	--	8.8
Less than 300	160.9	--	--	--	160.9
Total	169.7	--	--	--	169.7
All types					
More than 800	6,370.3	52.1	2,398.3	3,839.6	80.3
300-800	4,581.7	--	536.7	2,862.4	1,182.6
Less than 300	2,751.9	--	--	371.8	2,380.1
Total	13,703.9	52.1	2,935.0	7,073.8	3,643.0

Table 11.--Area of timberland by forest type, stand-age class, and operability class, Minnesota, 1977

(In thousand acres)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
less than 21	57.6	--	--	--	57.6
21-40	162.3	--	17.4	121.2	23.7
41-60	218.1	--	79.0	139.1	--
61-80	54.3	--	28.3	26.0	--
81-100	9.4	2.4	1.4	5.6	--
101-120	2.7	--	--	2.7	--
More than 120	--	--	--	--	--
Total	504.4	2.4	126.1	294.6	81.3
Red pine					
less than 21	28.9	--	--	1.9	27.0
21-40	85.8	--	6.0	23.5	56.3
41-60	40.7	--	22.9	17.8	--
61-80	44.3	--	10.6	33.7	--
81-100	33.0	--	13.5	19.5	--
101-120	8.5	--	7.2	1.3	--
More than 120	5.8	--	--	5.8	--
Total	247.0	--	60.2	103.5	83.3
White pine					
less than 21	3.3	--	--	--	3.3
21-40	5.1	--	3.8	1.3	--
41-60	11.0	--	2.8	8.2	--
61-80	19.5	--	3.7	15.8	--
81-100	20.2	--	9.4	10.8	--
101-120	6.5	--	5.2	1.3	--
More than 120	--	--	--	--	--
Total	65.6	--	24.9	37.4	3.3
Balsam fir					
less than 21	132.7	--	--	1.6	131.1
21-40	188.0	--	13.7	78.2	96.1
41-60	413.1	--	73.5	339.6	--
61-80	92.0	--	18.8	73.2	--
81-100	22.3	--	6.8	15.5	--
101-120	9.5	--	6.8	2.7	--
More than 120	--	--	--	--	--
Total	857.6	--	119.6	510.8	227.2

(Table 11 continued on the next page)

(Table 11 continued)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
White spruce					
less than 21	33.8	--	--	--	33.8
21-40	8.7	--	--	4.6	4.1
41-60	22.6	--	1.6	21.0	--
61-80	10.5	--	0.7	9.8	--
81-100	2.5	--	1.3	1.2	--
101-120	1.1	--	--	1.1	--
More than 120	--	--	--	--	--
Total	79.2	--	3.6	37.7	37.9
Black spruce					
less than 21	172.4	--	--	--	172.4
21-40	335.3	--	--	16.3	319.0
41-60	218.2	--	21.1	123.1	74.0
61-80	176.4	--	10.9	145.3	20.2
81-100	110.1	--	2.7	94.7	12.7
101-120	17.1	--	1.6	12.8	2.7
More than 120	12.5	--	--	12.5	--
Total	1,042.0	--	36.3	404.7	601.0
Northern white-cedar					
less than 21	23.0	--	--	5.4	17.6
21-40	46.5	--	--	9.4	37.1
41-60	67.3	--	11.7	44.0	11.6
61-80	108.1	--	7.7	96.3	4.1
81-100	114.6	--	10.3	100.0	4.3
101-120	60.4	--	6.7	53.7	--
More than 120	78.7	--	15.1	63.6	--
Total	498.6	--	51.5	372.4	74.7
Tamarack					
less than 21	112.0	--	--	--	112.0
21-40	80.2	--	--	6.8	73.4
41-60	99.9	--	10.7	61.9	27.3
61-80	63.3	--	7.3	46.8	9.2
81-100	44.4	--	2.7	39.2	2.5
101-120	38.1	--	2.8	35.3	--
More than 120	28.0	--	1.6	26.4	--
Total	465.9	--	25.1	216.4	224.4
Oak-hickory					
less than 21	66.7	--	--	--	66.7
21-40	69.7	--	25.7	30.4	13.6
41-60	277.1	--	132.5	144.6	--
61-80	242.4	5.5	153.4	83.5	--
81-100	186.4	15.0	114.4	57.0	--
101-120	47.6	4.0	27.9	15.7	--
More than 120	7.6	--	6.1	1.5	--
Total	897.5	24.5	460.0	332.7	80.3
Elm-ash-cottonwood					
less than 21	99.3	--	--	--	99.3
21-40	87.0	--	14.5	22.6	49.9
41-60	195.9	--	51.4	139.6	4.9
61-80	187.7	1.4	51.0	133.7	1.6
81-100	116.7	--	20.4	96.3	--
101-120	32.3	--	4.1	28.2	--
More than 120	19.3	--	4.5	14.8	--
Total	738.2	1.4	145.9	435.2	155.7

(Table 11 continued on the next page)

(Table 11 continued)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Maple-basswood					
less than 21	83.5	--	--	0.5	83.0
21-40	133.8	--	26.8	75.7	31.3
41-60	419.3	3.0	164.5	251.8	--
61-80	376.2	7.8	187.4	181.0	--
81-100	180.6	5.6	98.9	76.1	--
101-120	66.9	6.0	34.4	25.1	1.4
More than 120	25.5	--	9.8	15.7	--
Total	1,285.8	22.4	521.8	625.9	115.7
Aspen					
less than 21	1,253.0	--	--	13.3	1,239.7
21-40	1,264.4	--	155.6	852.5	256.3
41-60	2,132.9	--	652.1	1,472.4	8.4
61-80	555.1	1.4	222.2	331.5	--
81-100	90.9	--	34.1	56.8	--
101-120	4.5	--	--	4.5	--
More than 120	4.3	--	1.4	--	2.9
Total	5,305.1	1.4	1,065.4	2,731.0	1,507.3
Paper birch					
less than 21	91.8	--	--	25.8	66.0
21-40	151.0	--	24.2	95.9	30.9
41-60	510.6	--	113.3	397.3	--
61-80	187.6	--	69.5	118.1	--
81-100	37.5	--	10.8	26.7	--
101-120	20.2	--	1.3	18.9	--
More than 120	--	--	--	--	--
Total	998.7	--	219.1	682.7	96.9
Balsam poplar					
less than 21	143.3	--	--	--	143.3
21-40	133.9	--	6.7	87.6	39.6
41-60	199.2	--	45.3	152.5	1.4
61-80	63.6	--	17.9	45.7	--
81-100	8.6	--	5.6	3.0	--
101-120	--	--	--	--	--
More than 120	--	--	--	--	--
Total	548.6	--	75.5	288.8	184.3
Nonstocked					
less than 21	160.6	--	--	--	160.6
21-40	2.9	--	--	--	2.9
41-60	4.8	--	--	--	4.8
61-80	1.4	--	--	--	1.4
81-100	--	--	--	--	--
101-120	--	--	--	--	--
More than 120	--	--	--	--	--
Total	169.7	--	--	--	169.7
All types					
less than 21	2,461.9	--		48.5	2,413.4
21-40	2,754.6	--	294.4	1,426.0	1,034.2
41-60	4,830.7	3.0	1,382.4	3,312.9	132.4
61-80	2,182.4	16.1	789.4	1,340.4	36.5
81-100	977.2	23.0	332.3	602.4	19.5
101-120	315.4	10.0	98.0	203.3	4.1
More than 120	181.7	--	38.5	140.3	2.9
Total	13,703.9	52.1	2,935.0	7,073.8	3,643.0

Table 12.--Area of timberland by forest type, ownership class, and operability class, Minnesota, 1977

(In thousand acres)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
National Forest	116.9	2.4	20.1	69.7	24.7
Other federal	12.1	--	5.3	5.4	1.4
Indian	5.2	--	2.8	1.1	1.3
State	93.8	--	27.9	47.9	18.0
County and municipal	82.4	--	18.9	52.2	11.3
Forest industry	52.4	--	10.9	32.9	8.6
Farmer	80.9	--	24.0	49.2	7.7
Miscellaneous private	60.7	--	16.2	36.2	8.3
Total	504.4	2.4	126.1	294.6	81.3
Red pine					
National Forest	130.7	--	31.3	35.3	64.1
Other federal	2.7	--	1.4	1.3	--
Indian	8.8	--	6.4	2.4	--
State	23.7	--	2.3	14.6	6.8
County and municipal	24.5	--	6.5	15.6	2.4
Forest industry	13.5	--	2.5	7.4	3.6
Farmer	21.5	--	5.7	11.8	4.0
Miscellaneous private	21.6	--	4.1	15.1	2.4
Total	247.0	--	60.2	103.5	83.3
White pine					
National Forest	19.4	--	14.2	5.2	--
Other federal	1.4	--	--	1.4	--
Indian	7.5	--	2.8	4.7	--
State	2.6	--	--	1.2	1.4
County and municipal	4.4	--	--	4.4	--
Forest industry	5.1	--	--	5.1	--
Farmer	16.7	--	6.5	10.2	--
Miscellaneous private	8.5	--	1.4	5.2	1.9
Total	65.6	--	24.9	37.4	3.3
Balsam fir					
National Forest	184.4	--	63.6	89.2	31.6
Other federal	6.1	--	--	2.8	3.3
Indian	23.0	--	4.1	10.9	8.0
State	198.6	--	11.3	116.9	70.4
County and municipal	196.4	--	22.2	129.2	45.0
Forest industry	80.6	--	5.5	46.8	28.3
Farmer	75.6	--	4.8	47.3	23.5
Miscellaneous private	92.9	--	8.1	67.7	17.1
Total	857.6	--	119.6	510.8	227.2

(Table 12 continued on next page)

(Table 12 continued)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
White spruce					
National Forest	26.3	--	0.7	4.7	20.9
Other federal	1.4	--	--	1.4	--
Indian	6.5	--	--	5.0	1.5
State	22.3	--	1.6	11.3	9.4
County and municipal	4.1	--	--	4.1	--
Forest industry	2.7	--	--	1.3	1.4
Farmer	7.8	--	--	3.1	4.7
Miscellaneous private	8.1	--	1.3	6.8	--
Total	79.2	--	3.6	37.7	37.9
Black spruce					
National Forest	184.4	--	15.0	85.0	84.4
Other federal	11.1	--	--	4.4	6.7
Indian	51.4	--	--	17.9	33.5
State	421.3	--	14.2	163.7	243.4
County and municipal	160.6	--	3.0	47.6	110.0
Forest industry	66.8	--	--	25.8	41.0
Farmer	69.9	--	4.1	28.3	37.5
Miscellaneous private	76.5	--	--	32.0	44.5
Total	1,042.0	--	36.3	404.7	601.0
Northern white-cedar					
National Forest	61.5	--	15.7	41.5	4.3
Other federal	7.8	--	--	7.8	--
Indian	48.7	--	2.7	40.2	5.8
State	202.0	--	14.2	147.2	40.6
County and municipal	68.7	--	2.8	49.6	16.3
Forest industry	49.9	--	7.8	37.6	4.5
Farmer	25.4	--	2.8	21.1	1.5
Miscellaneous private	34.6	--	5.5	27.4	1.7
Total	498.6	--	51.5	372.4	74.7
Tamarack					
National Forest	7.2	--	--	4.5	2.7
Other federal	5.6	--	--	2.4	3.2
Indian	25.5	--	--	19.8	5.7
State	223.8	--	12.2	101.8	109.8
County and municipal	73.1	--	--	35.1	38.0
Forest industry	10.0	--	--	6.7	3.3
Farmer	76.3	--	6.9	29.0	40.4
Miscellaneous private	44.4	--	6.0	17.1	21.3
Total	465.9	--	25.1	216.4	224.4
Oak-hickory					
National Forest	11.1	4.7	6.4	--	--
Other federal	6.6	--	2.6	4.0	--
Indian	8.6	--	--	5.6	3.0
State	66.3	3.0	33.5	24.0	5.8
County and municipal	38.9	--	7.3	21.1	10.5
Forest industry	10.3	--	--	4.1	6.2
Farmer	583.3	14.4	320.6	205.2	43.1
Miscellaneous private	172.4	2.4	89.6	68.7	11.7
Total	897.5	24.5	460.0	332.7	80.3
Elm-ash-cottonwood					
National Forest	44.6	--	11.5	30.8	2.3
Other federal	15.9	--	4.4	10.5	1.0
Indian	19.0	--	1.5	11.2	6.3
State	123.4	--	23.1	63.7	36.6
County and municipal	122.9	--	11.0	82.9	29.0
Forest industry	38.5	--	5.7	25.3	7.5
Farmer	234.6	1.4	64.9	137.9	30.4
Miscellaneous private	139.3	--	23.8	72.9	42.6
Total	738.2	1.4	145.9	435.2	155.7

(Table 12 continued on next page)

(Table 12 continued)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Maple-basswood					
National Forest	98.7	--	64.9	31.0	2.8
Other federal	11.7	--	3.8	7.9	--
Indian	24.9	1.4	12.4	9.7	1.4
State	117.3	--	30.7	73.7	12.9
County and municipal	163.1	--	40.3	105.5	17.3
Forest industry	40.2	--	11.7	21.4	7.1
Farmer	587.0	16.3	254.8	259.0	56.9
Miscellaneous private	242.9	4.7	103.2	117.7	17.3
Total	1,285.8	22.4	521.8	625.9	115.7
Aspen					
National Forest	598.5	--	174.6	300.2	123.7
Other federal	46.9	--	6.8	28.1	12.0
Indian	187.2	--	41.4	85.9	59.9
State	847.1	--	117.1	471.2	258.8
County and municipal	1,058.2	--	195.0	599.7	263.5
Forest industry	315.8	--	54.5	141.4	119.9
Farmer	1,279.2	--	271.1	609.6	398.5
Miscellaneous private	972.2	1.4	204.9	494.9	271.0
Total	5,305.1	1.4	1,065.4	2,731.0	1,507.3
Paper birch					
National Forest	196.5	--	48.7	146.6	1.2
Other federal	8.7	--	2.7	4.6	1.4
Indian	26.9	--	8.6	12.8	5.5
State	130.0	--	20.4	94.5	15.1
County and municipal	224.0	--	53.9	153.1	17.0
Forest industry	49.0	--	5.9	26.9	16.2
Farmer	161.8	--	49.1	91.6	21.1
Miscellaneous private	201.8	--	29.8	152.6	19.4
Total	998.7	--	219.1	682.7	96.9
Balsam poplar					
National Forest	--	--	--	--	--
Other federal	11.5	--	--	6.8	4.7
Indian	20.3	--	2.8	12.1	5.4
State	140.3	--	18.4	66.6	55.3
County and municipal	97.4	--	22.1	61.1	14.2
Forest industry	29.0	--	6.9	14.9	7.2
Farmer	152.2	--	17.1	77.8	57.3
Miscellaneous private	97.9	--	8.2	49.5	40.2
Total	548.6	--	75.5	288.8	184.3
Nonstocked					
National Forest	33.4	--	--	--	33.4
Other federal	4.7	--	--	--	4.7
Indian	3.3	--	--	--	3.3
State	39.3	--	--	--	39.3
County and municipal	23.4	--	--	--	23.4
Forest industry	8.2	--	--	--	8.2
Farmer	35.8	--	--	--	35.8
Miscellaneous private	21.6	--	--	--	21.6
Total	169.7	--	--	--	169.7
All types					
National Forest	1,713.6	7.1	466.7	843.7	396.1
Other federal	154.2	--	27.0	88.8	38.4
Indian	466.8	1.4	85.5	239.3	140.6
State	2,651.8	3.0	326.9	1,398.3	923.6
County and municipal	2,342.1	--	383.0	1,361.2	597.9
Forest industry	772.0	--	111.4	397.6	263.0
Farmer	3,408.0	32.1	1,032.4	1,581.1	762.4
Miscellaneous private	2,195.4	8.5	502.1	1,163.8	521.0
Total	13,703.9	52.1	2,935.0	7,073.8	3,643.0

Table 13.--Area of timberland by distance from major wood-using center and operability class, Minnesota, 1977

(In thousand acres)

Wood-using center and distance (miles)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Bemidji					
Less than 20	476.9	--	153.6	231.7	91.6
20-50	2,105.2	14.1	568.5	1,047.9	474.7
More than 50	11,121.8	38.0	2,212.9	5,794.2	3,076.7
Brainerd					
Less than 20	358.2	1.4	123.3	172.1	61.4
20-50	1,613.8	4.7	395.1	846.5	367.5
More than 50	11,731.9	46.0	2,416.6	6,055.2	3,214.1
Cloquet					
Less than 20	398.5	--	39.9	219.3	139.3
20-50	1,796.9	--	272.0	997.1	527.8
More than 50	11,508.5	52.1	2,623.1	5,857.4	2,975.9
Cook					
Less than 20	525.2	--	85.6	291.6	148.0
20-50	2,355.1	--	320.4	1,305.4	729.3
More than 50	10,823.6	52.1	2,529.0	5,476.8	2,765.7
Grand Rapids					
Less than 20	477.3	--	113.9	259.9	103.5
20-50	2,609.4	7.1	514.2	1,320.6	767.5
More than 50	10,617.2	45.0	2,306.9	5,493.3	2,772.0
International Falls					
Less than 20	175.9	--	6.9	94.0	75.0
20-50	1,284.6	--	139.1	707.2	438.3
More than 50	12,243.4	52.1	2,789.0	6,272.6	3,129.7
Sartell					
Less than 20	78.4	--	32.8	33.7	11.9
20-50	604.5	10.6	218.9	249.6	125.4
More than 50	13,021.0	41.5	2,683.3	6,790.5	3,505.7
Twin cities					
Less than 20	12.5	--	4.6	4.7	3.2
20-50	237.7	4.3	76.9	126.7	29.8
More than 50	13,453.7	47.8	2,853.5	6,942.4	3,610.0
Winona					
Less than 20	129.6	5.7	94.7	21.9	7.3
20-50	278.7	8.7	156.0	86.7	27.3
More than 50	13,295.6	37.7	2,684.3	6,965.2	3,608.4
Closest wood-using center					
Less than 20	2,632.3	7.1	655.2	1,328.8	641.2
20-50	8,068.7	33.4	1,688.3	4,195.0	2,152.0
More than 50	3,002.9	11.6	591.5	1,550.0	849.8

Table 14.--Growing-stock volume on timberland by operability class component and forest type, Minnesota, 1977

(In thousand cubic feet)

Operability class component	All types	Forest type: Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
Stand area (acres)									
More than 60	3,101,191	112,702	43,496	25,911	73,675	14,187	124,282	49,763	37,193
10-60	3,984,889	169,663	204,145	18,780	193,729	7,974	138,255	98,471	70,938
Less than 10	4,375,948	277,972	131,795	59,451	411,744	27,800	231,005	230,334	96,006
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Growing-stock volume per acre (cubic feet/acre)									
More than 800	8,540,129	449,702	353,674	101,651	473,440	33,326	255,923	254,781	82,712
300-800	2,557,522	105,836	24,232	2,491	183,958	14,249	181,916	104,963	96,390
Less than 300	364,377	4,799	1,530	--	21,750	2,386	55,703	18,824	25,035
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Sawtimber volume per acre (board feet/acre)									
More than 3000	4,128,986	253,002	314,874	98,539	194,137	27,382	28,862	153,298	12,823
1100-3000	3,697,279	165,660	32,440	5,603	263,595	10,478	118,991	127,568	58,244
Less than 1100	3,635,763	141,675	32,122	--	221,416	12,101	345,689	97,702	133,070
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Percent cull trees (percent)									
Less than 20	8,073,947	515,942	313,234	82,477	563,440	38,812	447,773	224,023	159,739
20-50	3,109,393	43,485	65,238	19,241	106,768	10,504	43,291	143,934	41,186
More than 50	278,688	910	964	2,424	8,940	645	2,478	10,611	3,212
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Average d.b.h. of growing-stock trees (inches)									
More than 10	1,504,257	34,592	110,405	23,050	23,552	8,078	1,558	20,626	2,383
6-10	9,702,762	506,653	263,745	81,092	646,861	39,847	407,224	347,174	170,043
Less than 6	255,009	19,092	5,286	--	8,735	2,036	84,760	10,768	31,711
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Average merchantable height of growing-stock trees (feet)									
More than 28	8,883,170	352,613	328,612	93,871	374,299	35,578	172,505	75,111	71,044
16-28	2,566,044	206,281	50,776	10,271	304,712	14,188	320,378	297,323	132,217
Less than 16	12,814	1,443	48	--	137	195	659	6,134	876
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137
Distance to road (miles)									
Less than 1/4	3,831,086	279,029	155,436	37,557	154,189	17,518	76,882	73,573	42,199
1/4 - 3/4	5,330,378	235,178	156,834	60,759	329,841	13,227	208,146	144,808	82,904
More than 3/4	2,300,564	46,130	67,166	5,826	195,118	19,216	208,514	160,187	79,034
All classes	11,462,028	560,337	379,436	104,142	679,148	49,961	493,542	378,568	204,137

(Table 14 continued on the next page)

(Table 14 continued)

Operability class component	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
Stand area (acres)							
More than 60	421,661	89,468	387,515	1,411,772	264,000	44,927	639
10-60	228,671	187,878	482,250	1,698,667	342,509	140,167	2,792
Less than 10	137,610	306,652	344,047	1,574,089	314,001	222,288	11,154
All classes	787,942	583,998	1,213,812	4,684,528	920,510	407,382	14,585
Growing-stock volume per acre (cubic feet/acre)							
More than 800	573,151	403,593	942,464	3,505,075	727,503	283,323	--
300-800	199,355	160,564	245,226	948,752	178,554	104,498	3,833
Less than 300	15,736	19,230	23,122	230,701	14,653	19,556	10,752
All classes	787,942	583,998	1,213,812	4,684,528	920,510	407,382	14,585
Sawtimber volume per acre (board feet/acre)							
More than 3000	427,011	214,645	761,761	1,315,242	186,259	141,148	--
1100-3000	245,439	221,335	308,133	1,610,990	[illegible]	134,441	1,063
Less than 1100	115,492	148,015	143,919	1,758,330	[illegible]	132,497	13,522
All classes	787,942	583,998	1,213,812	4,684,528	920,510	407,382	14,585
Percent cull trees (percent)							
Less than 20	531,282	400,823	667,017	3,045,765	724,414	297,216	5,994
20-50	228,891	162,700	460,409	1,399,135	[illegible]	[illegible]	3,799
More than 50	27,769	20,475	[illegible]	104,450	10,749	[illegible]	4,792
All classes	787,942	583,998	1,213,812	[illegible]	[illegible]	[illegible]	14,585
Average d.b.h. of growing-stock trees (inches)							
More than 10	313,924	[illegible]	[illegible]	346,778	[illegible]	43,305	4,189
6-10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9,007
Less than 6	433	[illegible]	2,712	[illegible]	[illegible]	[illegible]	589
All classes	[illegible]	[illegible]	1,213,812	[illegible]	[illegible]	[illegible]	14,585
Average merchantable height of growing-stock trees (feet)							
More than 32	628,214	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7,596
16-32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Less than 16	3[illegible]	3[illegible]	--	[illegible]	[illegible]	279	2[illegible]
All classes	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Distance to road (miles)							
Less than 1/4	[illegible]	241,734	[illegible]	[illegible]	[illegible]	[illegible]	4,414
1/4 - 3/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
More than 3/4	2,3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
All classes	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 15.--Growing-stock volume on timberland by forest type and operability class, Minnesota, 1977

(In thousand cubic feet)

Forest type	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack pine	560,337	6,270	197,795	327,235	29,037
Red pine	379,436	--	120,104	191,509	67,823
White pine	104,142	--	41,868	61,835	439
Balsam fir	679,148	--	136,387	473,286	69,475
White spruce	49,961	--	3,939	40,970	5,052
Black spruce	493,542	--	37,626	336,152	119,764
Northern white-cedar	378,568	--	57,048	303,692	17,828
Tamarack	204,137	--	21,585	143,603	38,949
Oak-hickory	787,942	29,631	492,176	247,847	18,288
Elm-ash-cottonwood	583,998	1,985	154,685	387,865	39,463
Maple-basswood	1,213,812	30,793	625,428	524,750	32,841
Aspen	4,684,528	3,214	1,492,086	2,787,849	401,379
Paper birch	920,510	--	252,728	638,621	29,161
Balsam poplar	407,382	--	110,123	257,452	39,807
Nonstocked	14,585	--	--	--	14,585
All types	11,462,028	71,893	3,743,578	6,722,666	923,891

Table 16.--Growing-stock volume on timberland in operability class II (medium) by limiting factor and forest type, Minnesota, 1977

(In thousand cubic feet)

Limiting factor	All types	Forest type							
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1	90,453	--	16,713	1,327	--	--	--	--	--
2	4,651	--	268	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--
4	37,684	--	--	--	--	--	--	--	--
5	139,339	16,964	--	9,531	--	--	--	2,369	--
6	--	--	--	--	--	--	--	--	--
7	105,828	--	14,875	1,706	--	--	--	--	--
1 & 2	5,829	--	--	--	--	--	--	--	--
1 & 3	2,716	--	--	--	--	--	--	--	--
1 & 4	61,770	--	--	--	--	--	--	1,211	--
1 & 5	231,303	29,386	30,187	2,071	9,100	--	--	7,767	--
1 & 6	--	--	--	--	--	--	--	--	--
1 & 7	92,306	8,876	8,189	2,652	--	1,807	--	--	--
2 & 3	2,455	--	--	--	--	--	--	--	--
2 & 4	7,445	--	--	--	--	--	--	--	--
2 & 5	1,027	--	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--	--	--
2 & 7	10,923	1,249	--	--	--	--	--	--	938
3 & 4	4,741	--	--	--	--	--	--	--	--
3 & 5	104,751	2,560	1,384	--	--	--	--	--	--
3 & 6	--	--	--	--	--	--	--	--	--
3 & 7	--	--	--	--	--	--	--	--	--
4 & 5	39,863	--	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--	--	--
4 & 7	102,931	--	--	--	--	--	--	--	--
5 & 6	4,317	2,616	--	--	--	--	--	--	--
5 & 7	354,817	30,431	1,765	8,957	17,642	--	2,491	2,176	--
6 & 7	--	--	--	--	--	--	--	--	--

(Table 16 continued on the next page)

(Table 16 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1	13,352	--	39,581	16,885	--	2,595	--
2	3,321	--	1,062	--	--	--	--
3	--	--	--	--	--	--	--
4	10,999	2,473	24,212	--	--	--	--
5	25,549	2,078	17,847	54,093	4,692	6,216	--
6	--	--	--	--	--	--	--
7	51,690	7,097	22,464	7,838	--	158	--
1 & 2	844	--	4,072	913	--	--	--
1 & 3	--	--	1,375	1,341	--	--	--
1 & 4	23,490	1,457	20,186	13,964	1,462	--	--
1 & 5	21,089	12,621	34,164	68,268	11,935	4,715	--
1 & 6	--	--	--	--	--	--	--
1 & 7	15,758	1,197	35,740	12,692	3,165	2,230	--
2 & 3	1,086	--	484	885	--	--	--
2 & 4	6,409	--	1,036	--	--	--	--
2 & 5	1,027	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--
2 & 7	6,262	1,272	1,202	--	--	--	--
3 & 4	--	--	1,131	3,610	--	--	--
3 & 5	19,975	--	8,310	54,876	17,646	--	--
3 & 6	--	--	--	--	--	--	--
3 & 7	--	--	--	--	--	--	--
4 & 5	3,136	1,476	11,922	23,329	--	--	--
4 & 6	--	--	--	--	--	--	--
4 & 7	35,151	--	37,383	30,397	--	--	--
5 & 6	1,701	--	--	--	--	--	--
5 & 7	55,268	8,179	66,727	148,954	6,078	6,149	--
6 & 7	--	--	--	--	--	--	--

(Table 16 continued on the next page)

(Table 16 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1 & 2 & 3	1,651	1,390	3,649	2,845	--	--	--
1 & 2 & 4	836	--	1,044	--	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--
1 & 2 & 7	--	--	2,585	--	--	--	--
1 & 3 & 4	--	--	935	2,686	--	--	--
1 & 3 & 5	13,038	11,835	14,458	99,568	19,551	13,793	--
1 & 3 & 6	--	--	--	--	--	--	--
1 & 3 & 7	--	--	--	3,812	--	--	--
1 & 4 & 5	2,900	4,405	8,648	33,289	5,781	3,106	--
1 & 4 & 6	--	--	--	--	--	--	--
1 & 4 & 7	8,568	3,334	27,758	26,945	2,244	4,799	--
1 & 5 & 6	--	--	4,416	1,770	--	--	--
1 & 5 & 7	13,057	17,759	47,598	154,064	28,675	18,979	--
1 & 6 & 7	--	--	--	--	--	--	--
2 & 3 & 4	2,916	--	979	--	--	--	--
2 & 3 & 5	4,918	936	876	5,720	--	--	--
2 & 3 & 6	--	--	--	--	--	--	--
2 & 3 & 7	1,218	--	623	861	--	--	--
2 & 4 & 5	897	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--
2 & 4 & 7	6,671	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--
2 & 5 & 7	--	968	982	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--
3 & 4 & 5	4,634	1,336	6,187	23,126	1,492	1,769	--
3 & 4 & 6	--	--	--	--	--	--	--
3 & 4 & 7	2,168	--	--	1,642	--	--	--
3 & 5 & 6	2,944	1,228	--	1,113	--	--	--
3 & 5 & 7	22,016	6,807	20,150	168,180	35,680	5,254	--
3 & 6 & 7	--	--	--	--	--	--	--
4 & 5 & 6	--	--	1,374	--	--	--	--
4 & 5 & 7	4,478	2,089	16,505	50,011	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--
5 & 6 & 7	--	--	4,852	--	--	--	--
4 or more	103,159	64,748	132,911	478,409	114,327	40,360	--
All factors	492,176	154,685	625,428	1,492,086	252,728	110,123	--

Table 17.--Growing-stock volume on timberland in operability class III (poor) by limiting factor and forest type, Minnesota, 1977

(In thousand cubic feet)

Limiting factor	All types	Forest type: Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1	2,204,759	175,270	108,101	54,024	171,699	16,485	30,663	105,985	25,119
2	2,676	--	277	--	--	--	--	--	398
3	1,295,655	48,796	8,950	--	40,021	1,988	59,905	10,327	16,769
4	75,389	--	--	--	1,295	--	--	1,368	839
5	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--
7	913,132	9,668	49,548	2,823	42,116	11,302	33,360	44,114	12,212
1 & 2	2,394	--	--	--	--	--	--	262	--
1 & 3	803,881	58,445	1,718	--	78,373	4,916	54,984	21,983	22,180
1 & 4	54,468	--	621	2,424	--	--	--	2,163	--
1 & 5	--	--	--	--	--	--	--	--	--
1 & 6	--	--	--	--	--	--	--	--	--
1 & 7	534,118	23,474	15,651	2,564	83,042	5,152	38,621	66,438	8,762
2 & 3	19,529	--	--	--	586	--	545	1,183	738
2 & 4	954	--	--	--	--	--	--	--	--
2 & 5	--	--	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--	--	--
2 & 7	--	--	--	--	--	--	--	--	--
3 & 4	24,810	--	--	--	--	--	--	637	--
3 & 5	54,570	536	3,374	--	535	--	18,817	--	6,622
3 & 6	--	--	--	--	--	--	--	--	--
3 & 7	368,885	708	--	--	23,920	--	36,598	16,926	24,900
4 & 5	--	--	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--	--	--
4 & 7	14,017	--	--	--	595	352	--	1,499	--
5 & 6	--	--	--	--	--	--	--	--	--
5 & 7	--	--	--	--	--	--	--	--	--
6 & 7	--	--	--	--	--	--	--	--	--

(Table 17 continued on the next page)

(Table 17 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1	104,153	171,954	232,198	718,283	180,217	110,608	--
2	869	--	720	--	412	--	--
3	68,363	39,574	50,698	773,042	153,870	23,352	--
4	12,458	6,157	30,675	20,728	1,869	--	--
5	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--
7	16,675	50,335	80,091	431,466	106,133	23,289	--
1 & 2	456	364	667	645	--	--	--
1 & 3	16,568	53,578	38,143	341,607	59,695	51,691	--
1 & 4	8,771	7,401	16,216	14,491	719	1,662	--
1 & 5	--	--	--	--	--	--	--
1 & 6	--	--	--	--	--	--	--
1 & 7	1,213	36,120	33,759	165,600	32,202	21,520	--
2 & 3	3,307	2,692	3,553	4,167	1,609	1,149	--
2 & 4	161	--	793	--	--	--	--
2 & 5	--	--	--	--	--	--	--
2 & 6	--	--	--	--	--	--	--
2 & 7	--	--	--	--	--	--	--
3 & 4	3,678	1,337	2,960	13,173	2,463	562	--
3 & 5	--	747	1,083	21,789	642	425	--
3 & 6	--	--	--	--	--	--	--
3 & 7	7,347	8,054	16,451	161,724	60,380	11,877	--
4 & 5	--	--	--	--	--	--	--
4 & 6	--	--	--	--	--	--	--
4 & 7	--	--	5,507	5,263	--	801	--
5 & 6	--	--	--	--	--	--	--
5 & 7	--	--	--	--	--	--	--
6 & 7	--	--	--	--	--	--	--

(Table 17 continued on the next page)

(Table 17 continued)

Limiting factor	All types	Forest type							
		Jack pine	Red pine	White pine	Balsam fir	White spruce	Black spruce	Northern white-cedar	Tamarack
1 & 2 & 3	27,079	483	--	--	2,496	--	3,005	1,594	1,650
1 & 2 & 4	1,149	--	--	--	--	--	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--	--	--
1 & 2 & 7	577	--	--	--	--	--	--	315	262
1 & 3 & 4	9,878	--	--	--	--	--	389	--	--
1 & 3 & 5	18,059	2,237	1,302	--	480	--	4,247	969	2,026
1 & 3 & 6	1,043	--	--	--	--	--	--	1,043	--
1 & 3 & 7	203,827	2,010	1,967	--	23,050	775	34,912	13,907	11,635
1 & 4 & 5	--	--	--	--	--	--	--	--	--
1 & 4 & 6	--	--	--	--	--	--	--	--	--
1 & 4 & 7	15,101	685	--	--	421	--	581	895	--
1 & 5 & 6	--	--	--	--	--	--	--	--	--
1 & 5 & 7	--	--	--	--	--	--	--	--	--
1 & 6 & 7	--	--	--	--	--	--	--	--	--
2 & 3 & 4	5,129	--	--	--	681	--	--	--	--
2 & 3 & 5	435	--	--	--	--	--	127	--	--
2 & 3 & 6	--	--	--	--	--	--	--	--	--
2 & 3 & 7	4,652	--	--	--	397	--	800	368	1,140
2 & 4 & 5	--	--	--	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--	--	--
2 & 4 & 7	--	--	--	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--	--	--
2 & 5 & 7	--	--	--	--	--	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--	--	--
3 & 4 & 5	--	--	--	--	--	--	--	--	--
3 & 4 & 6	--	--	--	--	--	--	--	--	--
3 & 4 & 7	2,125	--	--	--	--	--	--	--	--
3 & 5 & 6	608	--	--	--	--	--	--	608	--
3 & 5 & 7	38,042	4,923	--	--	2,723	--	13,489	3,015	6,683
3 & 6 & 7	521	--	--	--	--	--	--	521	--
4 & 5 & 6	--	--	--	--	--	--	--	--	--
4 & 5 & 7	--	--	--	--	--	--	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--	--	--
5 & 6 & 7	--	--	--	--	--	--	--	--	--
4 or more	25,204	--	--	--	856	--	5,109	7,572	1,668
All factors	6,722,666	327,235	191,509	61,835	473,286	40,970	336,152	303,692	143,603

(Table 17 continued on the next page)

(Table 17 continued)

Limiting factor	Forest type						
	Oak-hickory	Elm-ash-cottonwood	Maple-basswood	Aspen	Paper birch	Balsam poplar	Nonstocked
1 & 2 & 3	1,663	1,583	2,662	7,933	1,638	2,372	--
1 & 2 & 4	--	359	361	429	--	--	--
1 & 2 & 5	--	--	--	--	--	--	--
1 & 2 & 6	--	--	--	--	--	--	--
1 & 2 & 7	--	--	--	--	--	--	--
1 & 3 & 4	--	1,040	--	6,220	2,229	--	--
1 & 3 & 5	--	--	526	4,785	--	1,487	--
1 & 3 & 6	--	--	--	--	--	--	--
1 & 3 & 7	--	5,488	3,200	78,624	24,277	3,982	--
1 & 4 & 5	--	--	--	--	--	--	--
1 & 4 & 6	--	--	--	--	--	--	--
1 & 4 & 7	583	--	1,289	8,044	1,147	1,456	--
1 & 5 & 6	--	--	--	--	--	--	--
1 & 5 & 7	--	--	--	--	--	--	--
1 & 6 & 7	--	--	--	--	--	--	--
2 & 3 & 4	893	318	1,270	1,590	377	--	--
2 & 3 & 5	--	--	--	--	308	--	--
2 & 3 & 6	--	--	--	--	--	--	--
2 & 3 & 7	--	--	--	635	1,312	--	--
2 & 4 & 5	--	--	--	--	--	--	--
2 & 4 & 6	--	--	--	--	--	--	--
2 & 4 & 7	--	--	--	--	--	--	--
2 & 5 & 6	--	--	--	--	--	--	--
2 & 5 & 7	--	--	--	--	--	--	--
2 & 6 & 7	--	--	--	--	--	--	--
3 & 4 & 5	--	--	--	--	--	--	--
3 & 4 & 6	--	--	--	--	--	--	--
3 & 4 & 7	689	--	--	1,436	--	--	--
3 & 5 & 6	--	--	--	--	--	--	--
3 & 5 & 7	--	--	--	655	5,532	1,022	--
3 & 6 & 7	--	--	--	--	--	--	--
4 & 5 & 6	--	--	--	--	--	--	--
4 & 5 & 7	--	--	--	--	--	--	--
4 & 6 & 7	--	--	--	--	--	--	--
5 & 6 & 7	--	--	--	--	--	--	--
4 or more	--	764	1,928	5,520	1,590	197	--
All factors	247,847	387,865	524,750	2,787,849	638,621	257,452	--

Table 18.--Growing-stock volume on timberland by forest type, average growing-stock volume per acre, and operability class, Minnesota, 1977

(In thousand cubic feet)

Forest type and average growing-stock volume per acre (cu.ft. per acre)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
More than 800	449,702	6,270	189,260	251,741	2,431
300-800	105,836	--	8,535	75,011	22,290
Less than 300	4,799	--	--	483	4,316
Total	560,337	6,270	197,795	327,235	29,037
Red pine					
More than 800	353,674	--	117,910	183,289	52,475
300-800	24,232	--	2,194	7,943	14,095
Less than 300	1,530	--	--	277	1,253
Total	379,436	--	120,104	191,509	67,823
White pine					
More than 800	101,651	--	41,868	59,783	--
300-800	2,491	--	--	2,052	439
Less than 300	--	--	--	--	--
Total	104,142	--	41,868	61,835	439
Balsam fir					
More than 800	473,440	--	122,007	348,946	2,487
300-800	183,958	--	14,380	120,180	49,398
Less than 300	21,750	--	--	4,160	17,590
Total	679,148	--	136,387	473,286	69,475
White spruce					
More than 800	33,326	--	3,335	29,991	--
300-800	14,249	--	604	10,979	2,666
Less than 300	2,386	--	--	--	2,386
Total	49,961	--	3,939	40,970	5,052
Black spruce					
More than 800	255,923	--	32,398	222,400	1,125
300-800	181,916	--	5,228	108,589	68,099
Less than 300	55,703	--	--	5,163	50,540
Total	493,542	--	37,626	336,152	119,764
Northern white-cedar					
More than 800	254,781	--	41,972	212,809	--
300-800	104,963	--	15,076	82,882	7,005
Less than 300	18,824	--	--	8,001	10,823
Total	378,568	--	57,048	303,692	17,828
Tamarack					
More than 800	82,712	--	14,816	67,896	--
300-800	96,390	--	6,769	69,851	19,770
Less than 300	25,035	--	--	5,856	19,179
Total	204,137	--	21,585	143,603	38,949

(Table 18 continued on the next page)

(Table 18 continued)

Forest type and average growing-stock volume per acre (cu.ft. per acre)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Oak-hickory					
More than 800	573,151	29,631	400,734	142,786	--
300-800	199,055	--	91,442	97,712	9,901
Less than 300	15,736	--	--	7,349	8,387
Total	787,942	29,631	492,176	247,847	18,288
Elm-ash-cottonwood					
More than 800	403,599	1,985	126,597	275,017	--
300-800	160,569	--	28,088	106,768	25,713
Less than 300	19,830	--	--	6,080	13,750
Total	583,998	1,985	154,685	387,865	39,463
Maple-basswood					
More than 800	942,464	30,793	554,559	357,112	--
300-800	248,226	--	70,869	155,684	21,673
Less than 300	23,122	--	--	11,954	11,168
Total	1,213,812	30,793	625,428	524,750	32,841
Aspen					
More than 800	3,605,075	3,214	1,410,074	2,164,362	27,425
300-800	948,752	--	82,012	604,012	262,728
Less than 300	130,701	--	--	19,475	111,226
Total	4,684,528	3,214	1,492,086	2,787,849	401,379
Paper birch					
More than 800	727,303	--	236,110	487,009	4,184
300-800	178,554	--	16,618	144,366	17,570
Less than 300	14,653	--	--	7,246	7,407
Total	920,510	--	252,728	638,621	29,161
Balsam poplar					
More than 800	283,328	--	105,482	177,846	--
300-800	104,498	--	4,641	75,888	23,969
Less than 300	19,556	--	--	3,718	15,838
Total	407,382	--	110,123	257,452	39,807
Nonstocked					
More than 800	--	--	--	--	--
300-800	3,833	--	--	--	3,833
Less than 300	10,752	--	--	--	10,752
Total	14,585	--	--	--	14,585
All types					
More than 800	8,540,129	71,893	3,397,122	4,980,987	90,127
300-800	2,557,522	--	346,456	1,661,917	549,149
Less than 300	364,377	--	--	79,762	284,615
Total	11,462,028	71,893	3,743,578	6,722,666	923,891

Table 19.--Growing-stock volume on timberland by forest type, stand-age class, and operability class, Minnesota, 1977

(In thousand cubic feet)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
less than 21	20,368	--	--	--	20,368
21-40	146,812	--	23,450	114,693	8,669
41-60	293,378	--	128,213	165,165	--
61-80	78,129	--	43,276	34,853	--
81-100	18,064	6,270	2,856	8,938	--
101-120	3,586	--	--	3,586	--
More than 120	--	--	--	--	--
Total	560,337	6,270	197,795	327,235	29,037
Red pine					
less than 21	6,216	--	--	3,374	2,842
21-40	103,585	--	7,399	31,205	64,981
41-60	66,964	--	39,614	27,350	--
61-80	95,350	--	20,657	74,693	--
81-100	73,032	--	35,619	37,413	--
101-120	18,304	--	16,815	1,489	--
More than 120	15,985	--	--	15,985	--
Total	379,436	--	120,104	191,509	67,823
White pine					
less than 21	439	--	--	--	439
21-40	7,227	--	5,717	1,510	--
41-60	19,772	--	7,347	12,425	--
61-80	31,937	--	4,346	27,591	--
81-100	33,386	--	15,501	17,885	--
101-120	11,381	--	8,957	2,424	--
More than 120	--	--	--	--	--
Total	104,142	--	41,868	61,835	439
Balsam fir					
less than 21	36,828	--	--	784	36,044
21-40	109,193	--	14,465	61,297	33,431
41-60	395,576	--	83,333	312,243	--
61-80	107,813	--	26,872	80,941	--
81-100	20,876	--	6,023	14,853	--
101-120	8,862	--	5,694	3,168	--
More than 120	--	--	--	--	--
Total	679,148	--	136,387	473,286	69,475

(Table 19 continued on the next page)

(Table 19 continued)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
White spruce					
less than 21	4,143	--	--	--	4,143
21-40	5,144	--	--	4,235	909
41-60	18,474	--	1,528	16,946	--
61-80	17,267	--	604	16,663	--
81-100	3,772	--	1,807	1,965	--
101-120	1,161	--	--	1,161	--
More than 120	--	--	--	--	--
Total	49,961	--	3,939	40,970	5,052
Black spruce					
less than 21	37,779	--	--	--	37,779
21-40	71,617	--	--	13,151	58,466
41-60	130,644	--	20,859	94,431	15,354
61-80	140,459	--	11,811	124,145	4,503
81-100	92,050	--	3,792	84,972	3,286
101-120	9,738	--	1,164	8,198	376
More than 120	11,255	--	--	11,255	--
Total	493,542	--	37,626	336,152	119,764
Northern white-cedar					
less than 21	6,982	--	--	3,158	3,824
21-40	14,933	--	--	5,801	9,132
41-60	42,831	--	8,529	30,790	3,512
61-80	75,700	--	7,853	66,994	853
81-100	100,252	--	14,870	84,875	507
101-120	56,881	--	7,537	49,344	--
More than 120	80,989	--	18,259	62,730	--
Total	378,568	--	57,048	303,692	17,828
Tamarack					
less than 21	18,077	--	--	--	18,077
21-40	16,879	--	--	4,016	12,863
41-60	55,318	--	9,548	39,745	6,025
61-80	37,801	--	5,822	30,349	1,630
81-100	27,636	--	1,882	25,400	354
101-120	27,720	--	2,313	25,407	--
More than 120	20,706	--	2,020	18,686	--
Total	204,137	--	21,585	143,603	38,949
Oak-hickory					
less than 21	14,893	--	--	--	14,893
21-40	47,465	--	24,776	19,294	3,395
41-60	271,060	--	158,744	112,316	--
61-80	232,943	6,729	163,312	62,902	--
81-100	170,353	18,297	112,913	39,143	--
101-120	45,965	4,605	28,152	13,208	--
More than 120	5,263	--	4,279	984	--
Total	787,942	29,631	492,176	247,847	18,288
Elm-ash-cottonwood					
less than 21	25,304	--	--	--	25,304
21-40	37,743	--	11,516	13,644	12,583
41-60	178,880	--	55,237	122,530	1,113
61-80	168,556	1,985	52,356	113,752	463
81-100	114,690	--	24,497	90,193	--
101-120	33,548	--	3,634	29,914	--
More than 120	25,277	--	7,445	17,832	--
Total	583,998	1,985	154,685	387,865	39,463

(Table 19 continued on the next page)

(Table 19 continued)

Forest type and stand-age class (years)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Maple-basswood					
less than 21	24,137	--	--	281	23,856
21-40	81,869	--	23,736	49,379	8,754
41-60	389,674	3,570	194,923	191,181	--
61-80	412,904	13,266	223,796	175,842	--
81-100	199,495	7,242	126,115	66,138	--
101-120	73,784	6,715	42,975	23,863	231
More than 120	31,949	--	13,883	18,066	--
Total	1,213,812	30,793	625,428	524,750	32,841
Aspen					
less than 21	327,865	--	--	6,897	320,968
21-40	1,021,807	--	201,460	744,928	75,419
41-60	2,461,244	--	904,347	1,551,905	4,992
61-80	729,649	3,214	332,150	394,285	--
81-100	138,177	--	52,213	85,964	--
101-120	3,870	--	--	3,870	--
More than 120	1,916	--	1,916	--	--
Total	4,684,528	3,214	1,492,086	2,787,849	401,379
Paper birch					
less than 21	20,643	--	--	2,320	18,323
21-40	113,100	--	24,629	77,633	10,838
41-60	516,511	--	130,173	386,338	--
61-80	198,266	--	82,096	116,170	--
81-100	44,759	--	14,291	30,468	--
101-120	27,231	--	1,539	25,692	--
More than 120	--	--	--	--	--
Total	920,510	--	252,728	638,621	29,161
Balsam poplar					
less than 21	29,927	--	--	--	29,927
21-40	80,705	--	7,538	63,843	9,324
41-60	205,886	--	67,884	137,446	556
61-80	77,526	--	24,463	53,063	--
81-100	13,187	--	10,087	3,100	--
101-120	151	--	151	--	--
More than 120	--	--	--	--	--
Total	407,382	--	110,123	257,452	39,807
Nonstocked					
less than 21	13,729	--	--	--	13,729
21-40	143	--	--	--	143
41-60	579	--	--	--	579
61-80	134	--	--	--	134
81-100	--	--	--	--	--
101-120	--	--	--	--	--
More than 120	--	--	--	--	--
Total	14,585	--	--	--	14,585
All types					
less than 21	587,330	--	--	16,814	570,516
21-40	1,858,222	--	344,686	1,204,629	308,907
41-60	5,046,791	3,570	1,810,279	3,200,811	32,131
61-80	2,404,434	25,194	999,414	1,372,243	7,583
81-100	1,049,729	31,809	422,466	591,307	4,147
101-120	322,182	11,320	118,931	191,324	607
More than 120	193,340	--	47,802	145,538	--
Total	11,462,028	71,893	3,743,578	6,722,666	923,891

Table 20.--Growing-stock volume on timberland by forest type, ownership class, and operability class, Minnesota, 1977

(In thousand cubic feet)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Jack Pine					
National Forest	104,691	6,270	41,314	46,828	10,279
Other federal	14,577	--	7,105	6,348	1,124
Indian	6,368	--	4,689	1,037	642
State	113,699	--	45,943	61,862	5,894
County and municipal	97,414	--	27,148	66,362	3,904
Forest industry	54,797	--	14,919	38,152	1,726
Farmer	97,578	--	35,637	59,664	2,277
Miscellaneous private	71,213	--	21,040	46,982	3,191
Total	560,337	6,270	197,795	327,235	29,037
Red pine					
National Forest	214,855	--	72,875	77,330	64,650
Other federal	4,157	--	2,610	1,547	--
Indian	17,005	--	12,419	4,586	--
State	25,125	--	3,298	20,220	1,607
County and municipal	41,008	--	12,164	28,183	661
Forest industry	16,026	--	3,993	11,802	231
Farmer	35,665	--	7,645	27,689	331
Miscellaneous private	25,595	--	5,100	20,152	343
Total	379,436	--	120,104	191,509	67,823
White pine					
National Forest	34,227	--	24,205	10,022	--
Other federal	1,119	--	--	1,119	--
Indian	13,621	--	6,050	7,571	--
State	2,041	--	--	1,602	439
County and municipal	7,090	--	--	7,090	--
Forest industry	6,966	--	--	6,966	--
Farmer	29,367	--	10,001	19,366	--
Miscellaneous private	9,711	--	1,612	8,099	--
Total	104,142	--	41,868	61,835	439
Balsam fir					
National Forest	143,532	--	60,083	75,099	8,350
Other federal	3,423	--	--	2,229	1,194
Indian	25,295	--	5,621	16,027	3,647
State	152,462	--	15,140	113,154	24,168
County and municipal	177,491	--	33,083	131,313	13,095
Forest industry	58,787	--	7,773	43,498	7,516
Farmer	47,877	--	4,243	36,674	6,960
Miscellaneous private	70,281	--	10,444	55,292	4,545
Total	679,148	--	136,387	473,286	69,475

(Table 20 continued on next page)

(Table 20 continued)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
White spruce					
National Forest	14,409	--	604	10,134	3,671
Other federal	2,469	--	--	2,469	--
Indian	2,859	--	--	2,859	--
State	12,147	--	1,528	10,145	474
County and municipal	4,063	--	--	4,063	--
Forest industry	1,217	--	--	940	277
Farmer	3,643	--	--	3,013	630
Miscellaneous private	9,154	--	1,807	7,347	--
Total	49,961	--	3,939	40,970	5,052
Black spruce					
National Forest	115,210	--	14,195	74,906	26,109
Other federal	5,034	--	--	3,269	1,765
Indian	16,271	--	--	11,929	4,342
State	198,004	--	16,361	139,156	42,487
County and municipal	61,665	--	2,793	37,319	21,553
Forest industry	29,998	--	--	21,371	8,627
Farmer	34,358	--	4,277	22,287	7,794
Miscellaneous private	33,002	--	--	25,915	7,087
Total	493,542	--	37,626	336,152	119,764
Northern white-cedar					
National Forest	49,820	--	17,325	31,185	1,310
Other federal	5,878	--	--	5,878	--
Indian	38,566	--	3,473	32,718	2,375
State	143,569	--	15,328	119,004	9,237
County and municipal	43,194	--	3,021	37,210	2,963
Forest industry	49,326	--	8,215	40,260	851
Farmer	20,522	--	3,918	15,971	633
Miscellaneous private	27,693	--	5,768	21,466	459
Total	378,568	--	57,048	303,692	17,828
Tamarack					
National Forest	7,003	--	--	5,051	1,952
Other federal	1,891	--	--	1,634	257
Indian	12,098	--	--	10,004	2,094
State	99,266	--	11,181	72,871	15,214
County and municipal	30,355	--	--	22,015	8,340
Forest industry	4,544	--	--	4,118	426
Farmer	29,863	--	6,009	17,150	6,704
Miscellaneous private	19,117	--	4,395	10,760	3,962
Total	204,137	--	21,585	143,603	38,949
Oak-hickory					
National Forest	13,451	4,874	8,577	--	--
Other federal	6,665	--	3,219	3,446	--
Indian	4,188	--	--	3,963	225
State	62,845	3,783	38,407	20,052	603
County and municipal	29,799	--	7,544	19,014	3,241
Forest industry	4,522	--	--	3,809	713
Farmer	504,310	17,654	330,248	144,786	11,622
Miscellaneous private	162,162	3,320	104,181	52,777	1,884
Total	787,942	29,631	492,176	247,847	18,288
Elm-ash-cottonwood					
National Forest	21,795	--	4,913	16,436	446
Other federal	23,281	--	7,037	16,122	122
Indian	16,645	--	1,524	13,289	1,832
State	98,302	--	26,536	61,983	9,783
County and municipal	100,918	--	12,844	80,000	8,074
Forest industry	32,374	--	7,889	23,278	1,207
Farmer	195,668	1,985	66,438	119,203	8,042
Miscellaneous private	95,015	--	27,504	57,554	9,957
Total	583,998	1,985	154,685	387,865	39,463

(Table 20 continued on next page)

(Table 20 continued)

Forest type and ownership class	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Maple-basswood					
National Forest	123,053	--	96,446	24,881	1,726
Other federal	11,261	--	4,061	7,200	--
Indian	25,620	1,657	14,135	9,096	732
State	104,122	--	35,127	66,758	2,237
County and municipal	150,990	--	49,366	95,899	5,725
Forest industry	33,053	--	15,175	15,977	1,901
Farmer	538,833	23,722	289,864	209,169	16,078
Miscellaneous private	226,880	5,414	121,254	95,770	4,442
Total	1,213,812	30,793	625,428	524,750	32,841
Aspen					
National Forest	696,787	--	293,227	377,293	26,267
Other federal	40,336	--	7,210	29,354	3,772
Indian	178,048	--	57,659	101,974	18,415
State	727,782	--	169,812	489,051	68,919
County and municipal	1,001,427	--	274,811	650,595	76,021
Forest industry	276,614	--	85,065	160,983	30,566
Farmer	981,431	--	344,488	533,319	103,624
Miscellaneous private	782,103	3,214	259,814	445,280	73,795
Total	4,684,528	3,214	1,492,086	2,787,849	401,379
Paper birch					
National Forest	179,066	--	50,912	127,002	1,152
Other federal	6,915	--	2,751	3,820	344
Indian	23,503	--	10,149	11,446	1,908
State	127,201	--	24,506	100,383	2,312
County and municipal	216,892	--	64,322	145,993	6,577
Forest industry	36,591	--	7,347	25,142	4,102
Farmer	138,081	--	57,941	73,993	6,147
Miscellaneous private	192,261	--	34,800	150,842	6,619
Total	920,510	--	252,728	638,621	29,161
Balsam poplar					
National Forest	1,295	--	1,059	228	8
Other federal	5,936	--	--	5,326	610
Indian	15,219	--	4,862	9,189	1,168
State	100,216	--	26,852	62,351	11,013
County and municipal	98,095	--	32,622	61,817	3,656
Forest industry	28,654	--	11,223	15,438	1,993
Farmer	98,203	--	22,903	61,760	13,540
Miscellaneous private	59,764	--	10,602	41,343	7,819
Total	407,382	--	110,123	257,452	39,807
Nonstocked					
National Forest	532	--	--	--	532
Other federal	733	--	--	--	733
Indian	418	--	--	--	418
State	2,904	--	--	--	2,904
County and municipal	3,415	--	--	--	3,415
Forest industry	1,236	--	--	--	1,236
Farmer	3,305	--	--	--	3,305
Miscellaneous private	2,042	--	--	--	2,042
Total	14,585	--	--	--	14,585
All types					
National Forest	1,719,726	11,144	685,735	876,395	146,452
Other federal	133,675	--	33,993	89,761	9,921
Indian	395,724	1,657	120,581	235,688	37,798
State	1,969,685	3,783	430,019	1,338,592	197,291
County and municipal	2,063,816	--	519,718	1,386,873	157,225
Forest industry	634,705	--	161,599	411,734	61,372
Farmer	2,758,704	43,361	1,183,612	1,344,044	187,687
Miscellaneous private	1,785,993	11,948	608,321	1,039,579	126,145
Total	11,462,028	71,893	3,743,578	6,722,666	923,891

Table 21.--Growing-stock volume on timberland by distance from major wood-using center and operability class, Minnesota, 1977

(In thousand cubic feet)

Wood-using center and distance (miles)	All classes	Operability class			
		I - Good	II - Medium	III - Poor	IV - Sapling-seedling and nonstocked
Bemidji					
Less than 20	484,703	--	215,727	245,075	23,901
20-50	2,075,099	22,490	802,617	1,142,264	107,728
More than 50	8,902,226	49,403	2,725,234	5,335,327	792,262
Brainerd					
Less than 20	320,159	3,214	148,028	152,858	16,059
20-50	1,317,320	6,669	470,369	749,071	91,211
More than 50	9,824,549	62,010	3,125,181	5,820,737	816,621
Cloquet					
Less than 20	257,905	--	45,274	177,038	35,593
20-50	1,343,768	--	323,639	886,111	134,018
More than 50	9,860,355	71,893	3,374,665	5,659,517	754,280
Cook					
Less than 20	472,761	--	124,246	312,602	35,913
20-50	1,983,300	--	468,535	1,305,516	209,249
More than 50	9,005,967	71,893	3,150,797	5,104,548	678,729
Grand Rapids					
Less than 20	461,147	--	171,397	263,844	25,906
20-50	2,305,190	11,144	752,072	1,362,644	179,330
More than 50	8,695,691	60,749	2,820,109	5,096,178	718,655
International Falls					
Less than 20	122,223	--	9,524	95,727	16,972
20-50	1,037,771	--	194,475	740,470	102,826
More than 50	10,302,034	71,893	3,539,579	5,886,469	804,093
Sartell					
Less than 20	54,462	--	31,108	20,603	2,751
20-50	456,864	14,759	231,590	181,649	28,866
More than 50	10,950,702	57,134	3,480,880	6,520,414	892,274
Twin cities					
Less than 20	6,760	--	4,081	2,516	163
20-50	209,506	4,684	78,769	116,907	9,146
More than 50	11,245,762	67,209	3,660,728	6,603,243	914,582
Winona					
Less than 20	116,284	6,584	95,572	12,688	1,440
20-50	245,631	10,303	166,898	61,933	6,497
More than 50	11,100,113	55,006	3,481,108	6,648,045	915,954
Closest wood-using center					
Less than 20	2,296,404	9,798	844,957	1,282,951	158,698
20-50	6,850,868	46,106	2,168,714	4,083,935	552,113
More than 50	2,314,756	15,989	729,907	1,355,780	213,080

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A method for estimating operability and location of the timber resource. Res. Pap. NC-273. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 52 p.

Operability is the relative ease or difficulty of managing or harvesting timber because of physical conditions in the stand or on the site. Using data collected during standard Statewide forest inventories, we developed a method for classifying timber by operability class based on seven operability components.

KEY WORDS: Management opportunities, Minnesota, forest inventory, prime forest land.

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Fire-Danger Rating and Observed Wildfire Behavior in the Northeastern United States

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FIRE-DANGER RATING AND OBSERVED WILDFIRE BEHAVIOR IN THE NORTHEASTERN UNITED STATES

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East Lansing, Michigan

Fire management expenditures are heavily affected by the success or failure of fire-danger rating systems. Presuppression activities, such as aircraft detection flights and pre-positioning and potential dispatching of firefighters, are guided by these rating systems' numerical values. Fire-danger rating systems, however, are based on simplified models of complex, natural phenomena. Consequently neither the models nor the resultant rating systems completely reflect physical reality. We need to establish the validity of any fire-danger rating system and determine the consequences of its inherent models and assumptions.

The National Fire-Danger Rating System (NFDRS) was established in 1972 and revised in 1978 (Deeming *et al.* 1977). Users of this system include all United States Federal agencies and 35 State agencies charged with forest and rangeland fire protection (Deeming 1983). We have already determined the capability of various fire-danger rating systems (primarily the NFDRS) to predict wildfire occurrence in the Northeastern States (Haines *et al.* 1983). This second phase of the study concentrates on a comparison of predicted values of potential behavior with two measures of observed fire behavior. It emphasizes the use of fire-danger rating as a management planning aid, but not, of course, as a predictor of the behavior of an individual fire.

The NFDRS permits managers to select one or more of 20 possible fuel models; most select those fuel models based on qualitative descriptions given in manuals. One difficulty with this procedure is that each fuel model is defined by a combination of 19 parameters. No one has adequately determined how various combinations of these parameters interact with each other or with the remainder of the system, where 114 equations are used to process 134 variables (Bradshaw *et al.* 1983). Thus, the physical response of each model may not coincide with what might be expected, based on the qualitative description.

As Rothermel (1983) suggests, it is possible to select a fuel model, not only from a description of the physical properties of the vegetation, but also from its known fire behavior characteristics. As Bradshaw *et al.* (1983) state, however, ". . . currently there is no common measurement of any fire phenomenon to correlate with NFDRS ratings." Thus, one objective of this study was to develop procedures for validating fire-danger rating systems. We chose to validate the models from the perspective of the whole system. The intent was to quantify real-world operational variability, in contrast to most published work that has addressed the accuracy of fuel moisture or fire behavior models through carefully controlled experiments (e.g., Andrews 1980, Simard *et al.* 1984, van Wagtendonk and Botti 1984). In our study, standard weather station data were used as system inputs, and wildfire report data were compared with system outputs. Another objective of this study was to determine which of the NFDRS fuel models best fit field observations of fire behavior in the Northeast.

Some investigators have suggested that comparing the NFDRS with observed fire activity is only a partial indicator of system efficacy. The NFDRS, it is argued, is supposed to represent an ambiguous concept termed "fire business." But, we must consider two facts. First, the NFDRS and fire activity are both fuel and weather dependent. Hence, a one-to-one mapping should be possible with a perfect system. Second, considering fire management attributes such as area burned or suppression effort adds a new dimension—suppression efficiency—a concept that the NFDRS makes no attempt to measure. We might expect relations to be stronger be-

tween the NFDRS and fire behavior than between the NFDRS and suppression-dependent measures, and tests of those relations indicate that this is indeed the case. Therefore, in NFDRS validation we are largely restricted to tests that use measures of fire behavior.

Validating a fire-danger rating system is a complex undertaking. A poor match between the predicted and observed data could result from inherent variability in the phenomenon studied, measurement errors, sampling error, a poorly devised fire-danger system or, more likely, some combination of these problems. There is no way to identify the dominant problem when validating an isolated system, unless one attempts to redesign the system's physical and mathematical composition and then retest. Including other independently developed systems in the analysis, however, provides an experimental control for an inplace, operational system. Unless there is a bias which favors a specific system, comparison is not affected by data quality. If no one system performs satisfactorily, all systems have failed or, more likely, the problem lies with the observational data. If one or more systems work well relative to the others, we can reasonably assume that the data are adequate and that success and failure lie within the design of the systems. Therefore, in addition to testing the primary system (NFDRS), we also tested comparable components from other systems.

METHODS

Data Collection and Procedures

We established seven study sites—three in Michigan, two in Wisconsin, and two in Pennsylvania. Each study area included a central fire weather station with a 35-mile[1] radius of surveillance. Simard (1972) found that distance did not seriously affect the reliability of most wildfire predictors up to 50 miles from the weather station. Each fire within the circles was reported on an information form we provided. Besides information usually found on standard fire report forms, our form contained the following items that might be used for comparisons with predicted values:

1. Character of the fire on arrival: smoldering, creeping, running, torching, spotting, or crowning;
2. Average rate of spread at the head of the fire at initial attack;
3. Method of spread rate determination: measured, estimated;
4. Average flame length at the head of the fire at initial attack;
5. Time of fire origin and time and size of fire at initial attack;
6. Cover type: grass, brush on well drained sites, brush on poorly drained sites, conifer slash, hardwood slash, old slash, oak-hickory, upland conifer, lowland conifer, upland hardwood-conifer, lowland hardwood-conifer.

The weather stations and all fire control organizations within the surveillance circles were visited twice a year to ensure quality observations. Rothermel and Rinehart (1983) recently compiled detailed field procedures and documentation necessary to verify fire behavior predictions. Although predating their report, most of our procedures paralleled their suggestions.

Our data base included 5,166 daily weather observations and 2,682 wildfires occurring between March 1973 and January 1977. Editing reduced the records because:

1. Suppression forces did not record essential information (777 fires).
2. The fire occurred before 10 a.m. or after 6 p.m., well before or after the 1 p.m. LST weather station observation (623 fires); observed fire behavior measurements were made soon after initial attack.
3. The ratio of the recorded rate of spread to a computed rate of spread based on area increase (Simard 1977) produced an unacceptable difference, i.e., outside the range ($0.33 \leq \text{ratio} \leq 3.0$) (337 fires).
4. The recorded information produced a calculated value of heat per unit area that was physically impossible, given the reported cover type (five fires with obvious recording errors). Heat per unit area can be derived from basic physical relationships if the rate of spread and flame length are known (Andrews and Rothermel 1982, Appendix A). In brief,

$$H = \frac{340\ F^{2.17}}{RS} \qquad (1)$$

[1]*Because all fire-danger rating systems were developed in English units and all fire managers presently do their day-to-day calculations by that means, we used English units in this analysis.*

Where

H = heat per unit area (BTU/ft^2),

F = flame length (ft),

RS = rate of spread (ft/min).

The relation and scaling of NFDRS components to measures of fire behavior (including heat per unit area) are given in our Appendix. After editing, a total of 940 fires remained in the sample (table 1).

Use of Individual Event Versus Grouped Data

We treated the field observations as a collection of individual events rather than as grouped data because the first approach produced significant statistical results, gave reasonable error terms, and made direct comparisons between indices possible. Although grouping the data by increments of index values yielded much higher apparent predictive accuracy, the number of increment groups ranged from 8 to 15, depending upon the predictive index. This caused difficulty in directly comparing statistical measures among indices and produced unreasonably small values for the standard errors of the estimate.

Tests of Fuel Models

The selection of a satisfactory fuel model(s) depends upon managerial needs, and it is unlikely that any one model could fulfill all possible needs. For a discussion of the physical composition of the 20 fuel models, see Deeming *et al.* (1977) and Bradshaw *et al.* (1983), or review the short general descriptions given below:

Fuel model	General description
A	Western annual grasses
B	California mixed chaparral
C	Pine grass savanna
D	Southern rough
E	Hardwoods (winter)
F	Intermediate brush
G	Short-needled pine (heavy dead)
H	Short-needled pine (normal dead)
I	Heavy logging slash
J	Intermediate logging slash
K	Light logging slash
L	Western perennial grass
N	Sawgrass
O	High pocosin

Table 1.--Fires by cover type, season, and location

Cover type	Fires	Total
	Number	Percent
Hardwoods	322	34
Grass	317	34
Brush	153	16
Upland conifer	54	6
Slash	38	4
Upland mixed	36	4
Other	20	2
Total	940	100
Season		
Spring	377	40
Summer	399	42
Fall	164	18

Location		Hardwoods	Brush	Grass	Upland conifer	Other
		Percent in cover type				
Michigan	199	31	5	30	14	20
Pennsylvania	430	45	32	15	1	7
Wisconsin	311	21	2	61	7	9

P	Southern pine plantation
Q	Alaskan black spruce
R	Hardwoods (summer)
S	Tundra
T	Sagebrush-grass
U	Western long-needled conifer

We conducted a series of tests to determine the capability of several fuel models in the NFDRS to satisfy a number of needs.

1. **Means**—Minimize the absolute difference between the average value predicted by the model and average observed fire behavior. Models that do well in this should be best for long-term planning, because average predicted fire behavior would most nearly match average observed behavior.
2. **Sensitivity**—Minimize the absolute difference between the standard deviation of fire behavior observations and the standard deviation of model predictions. Models that do well in this test would provide about the same level of resolution as the phenomenon being modeled and span about the same range.
3. **Overall Predictive Accuracy**—Explain the variability (R^2) of fire-behavior observations for all fires. Models that do well in this test would provide the most accurate daily fire behavior prediction in management areas that include many different fuel types.
4. **Cover Type Accuracy**—Explain the variability (R^2) of fire-behavior observations within various cover types. Models that do well in this test would provide the most accurate daily fire behavior predictions in management areas that were predominantly of one cover type.
5. **Calibration**—Minimize differences between the regression coefficients and their ideal values (0 and 1). Models that do well in this test would correspond most nearly to observed behavior and would require the least calibration.
6. **Robustness**—Minimize dispersion of fire behavior predictions relative to season, cover type, and location. Models that do well in this test would be well suited to the broadest possible application.

These tests compared the NFDRS Spread Component with the observed rate of spread and the Burning Index with the observed flame length. Five fuel models that performed poorly in preliminary tests (average $R^2 < 0.10$) were deleted from the complete analyses (A, C, L, R, and S). Because responses of models P and U were nearly identical in early tests, only U was tested for all criteria. Models I, J, and K were almost perfectly correlated to each other (although their positions on a fire characteristics chart differed). Models I and J were deleted because they represent heavier fuel loadings than are commonly found in the Northeast. The remaining 12 models (B, D, E, F, G, H, K, N, O, Q, T, and U) were subjected to all tests. Preliminary results from all models are included in this paper. This allows the reader to partially compare the performance of the deleted models with that of the models that underwent complete analysis.

Tests of Various Indices

This part of the study ensured experimental control by including three meteorological elements in the analysis. These weather elements provided baseline results against which we could compare the predictive capability of the more complex (and presumably superior) fire-danger rating systems. We also tested several fire-danger rating indices and their components that might relate to fire spread or energy release. These elements, indices, and components are listed below, and each is described in the Appendix.

Weather elements	
Relative humidity	(RH)
Windspeed	(WS)
Days since 0.10″ precipitation	(PRECIP)
The 1978 National Fire-Danger Rating System	(NFDRS)
1-hour timelag fuel moisture	(FM_1)
10-hour timelag fuel moisture	(FM_{10})
100-hour timelag fuel moisture	(FM_{100})
1,000-hour timelag fuel moisture	(FM_{1000})
Ignition Component	(IC)
Spread Component	(SC)
Energy Release Component	(ERC)
Burning Index	(BI)
The Canadian Forest Fire Weather Index	(Canadian)
Fine Fuel Moisture Code	(FFMC)
Duff Moisture Code	(DMC)
Drought Code	(DC)
Initial Spread Index	(ISI)
Adjusted Duff Moisture Code	(ADMC)
Fire Weather Index	(FWI)
The 1964 National Fire-Danger Rating System	(1964-FDRS)
Fine Fuel Moisture	(FFM)
Fine Fuel Spread Index	(FFSI)
Timber Spread Index	(TSI)
Buildup Index	(BUI)

Fire Load Index	(FLI)
Keetch-Byram Drought Index	(KBDI)

RESULTS AND ANALYSIS

Statistical Summary of Observed Fire Behavior

The 940 wildfires burned predominantly in hardwoods (34%), grass (34%), and brush (16%) (table 1). They occurred more often in spring (40%) and summer (42%) than in fall (18%). Wisconsin's fires developed mostly in grass (61%), Pennsylvania's mostly in hardwoods (45%) and brush (32%), and Michigan's in hardwoods (31%) and grass (30%). The mean rate of spread reported by observers was much the same for all cover types: all fires (9.6 ft/min), hardwoods (8.9), brush (8.3), grass (10.5), and upland conifer (12.3) (table 2). The highest reported rate of spread was 66 ft/min and the longest reported flame length was 20 feet. The computed mean heat per unit area for all fires (568 BTU/ft^2) was not significantly different from that of hardwoods (632) or upland conifer (775), but was significantly different from that of grass (330) and brush (1,078).

Intercorrelation Among Models

We computed correlation coefficients for the Spread Component and Energy Release Component for all combinations of the 20 fuel models (table 3). Generally, high intercorrelation suggested that the predictive performance of many models will reflect similar performance of many other models. Some models, such as I, J, and K, were almost perfectly intercorrelated in both comparisons, and in this sense they are redundant, although they do differ in terms of absolute values.

On the other hand, many models were highly intercorrelated either in Spread Component or Energy Release Component, but not in both. For example, when we compared predicted rate of spread of model E with that of model F, the correlation was r = 0.98; but for heat per unit area the correlation was significantly lower (r = 0.72). The difference is difficult to explain solely by examining the values of the critical parameters that determine the composition of the fuel models. The fuel bed depths for models E and F differ by a factor of 10 and the 1-hour fuel loadings differ by 60 percent. Although these parameters affect fire spread, these differences do not appear to affect model intercorrelation. But, factors influencing energy release, such as fuel loadings for the 10-hour, 100-hour, and especially the live fuels, are quite different. This may account for the lowered intercorrelation between fuel models E and F for energy release, but there are many complex relationships among the parameters within each model and simple explanations are likely to be inadequate. See Rothermel (1972) for a review of fuel characteristics that influence fire behavior and Bradshaw *et al.* (1983) for a listing of the physical attributes of each fuel model.

This discussion demonstrates the problem facing fire managers when they attempt to select a fuel model by relying on verbal descriptions or listings of physical attributes. Without more definitive information, the selection process degenerates to a complex guessing game.

Table 2.--Observed and predicted means and standard deviations of rate of spread and heat per unit area

	Observations			
	Rate of spread		Heat per unit area	
	Mean	Standard deviation	Mean	Standard deviation
	Ft/min		BTU/ft^2 [2]	
All fires	9.6	9.0	568	1,007
Cover Type				
Hardwoods	8.9 [1]	7.5	632 [1]	1,000
Brush	8.3 [1]	7.0	1,078	1,335
Grass	10.5 [1]	10.3	330	812
Upland conifer	12.3 [2]	14.4	775 [1]	1,767

	Predictions			
Models	Mean	Standard deviation	Mean	Standard deviation
A	53.5	37.9	32 [2]	20
B	11.3	6.9	435 [2]	200
C	12.2	11.0	238	105
D	27.3	20.0	905 [2]	303
E	9.4 [1]	7.1	458 [2]	103
F	10.0 [1]	5.9	250	113
G	10.9	7.6	530 [1]	303
H	3.1	2.2	310	155
I	26.4	13.9	4,413	1,320
J	17.9	9.4	2,680	743
K	9.3 [1]	5.0	873	260
L	53.5	40.2	63	38
N	62.3	42.5	440	98
O	29.0	26.5	933	223
P	5.7	4.2	548 [1]	118
Q	23.5	16.8	818	228
R	2.5	2.0	300	103
S	7.0	5.7	275	95
T	27.8	23.7	163	105
U	6.1	4.3	530 [1]	150

[1] No significant difference between this mean and the mean of all fires at $P < 0.001$.

[2] No significant difference between this mean and the mean of all fires at $P < 0.01$.

Table 3.--Intercorrelation of the 20 NFDRS fuel models for Spread Component and Energy Release Component (sample size = 940)

NFDRS MODEL COMPARISONS
(r x 100)

SPREAD COMPONENT CORRELATIONS

	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q	R	S	T	U	
A		74	79	79	75	74	73	76	51	51	51	98	69	77	78	81	81	80	76	77	A
B	43		93	94	96	98	96	96	86	86	86	80	96	91	95	94	93	93	90	96	B
C	95	51		99	98	95	96	98	74	74	74	85	95	96	99	99	99	99	94	98	C
D	95	36	97		99	96	98	99	77	77	77	86	97	94	99	99	99	99	93	99	D
E	91	71	93	88		98	99	99	85	85	85	81	98	94	99	98	98	98	93	99	E
F	44	95	50	36	72		98	98	88	88	88	81	99	92	97	96	95	94	91	98	F
G	32	52	37	31	49	65		99	88	88	89	79	99	92	99	97	96	96	92	99	G
H	49	67	54	46	68	79	96		84	84	84	82	98	94	99	99	98	98	93	99	H
I	38	75	45	36	63	85	94	97		99	99	57	88	71	81	77	74	73	73	84	I
J	39	79	47	36	66	88	91	96	99		99	57	88	71	81	77	74	73	73	84	J
K	38	75	45	36	64	85	94	97	99	99		57	88	71	81	77	74	73	74	84	K
L	99	40	96	95	90	41	30	47	36	37	36		77	83	84	87	87	86	83	83	L
N	78	83	85	78	95	78	48	65	67	69	67	76		90	97	97	95	95	90	98	N
O	64	78	70	61	83	87	81	92	92	93	92	62	83		95	94	96	96	97	94	O
P	91	66	96	92	98	68	51	69	63	65	63	90	93	84		99	99	99	94	99	P
Q	84	68	89	85	94	74	69	83	78	79	78	83	90	93	97		99	99	92	99	Q
R	95	47	98	97	93	51	44	61	51	52	51	95	82	74	97	93		99	94	98	R
S	85	55	89	87	89	63	73	83	75	74	75	84	81	87	93	97	94		94	98	S
T	94	54	90	86	89	53	24	45	37	39	37	94	80	67	88	79	87	75		93	T
U	74	87	80	70	93	91	62	80	80	83	80	72	94	93	92	93	81	85	77		U
	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q	R	S	T	U	

ENERGY RELEASE COMPONENT CORRELATIONS

The Fire Characteristics Chart

The fire characteristics chart (fig. 1) illustrates three primary characteristics of fire activity—rate of spread, flame length, and heat per unit area (Andrews and Rothermel 1982). The chart allows us to visualize fire behavior in two-dimensional space. Ellipses on this chart show the means and standard deviations of both observed and predicted fire behavior. Because some of the distributions displayed are skewed, the elliptical nature of the joint standard distributions may not be entirely representative in some cases. However, an elliptical approximation appears quite satisfactory for purposes of illustration.

Scaling on the fire characteristics chart can be either logarithmic or linear. With a logarithmic scale (fig. 1), the straight diagonal lines represent flame length and the elliptical standard deviation envelopes are distorted. With a linear scale, the flame length lines are curved and the ellipses appear normal (fig. 2). The logarithmic scale allows the display of a wider range of behavior. Main and Haines (1983) have demonstrated the chart's usefulness in selecting fuel models, showing observed fire behavior, and illustrating means and standard deviations.

Overall fire severity, as well as the character of the fire, may be inferred from a fire's position on the chart. A number of descriptors of fire behavior can locate that point: the NFDRS Spread Component.

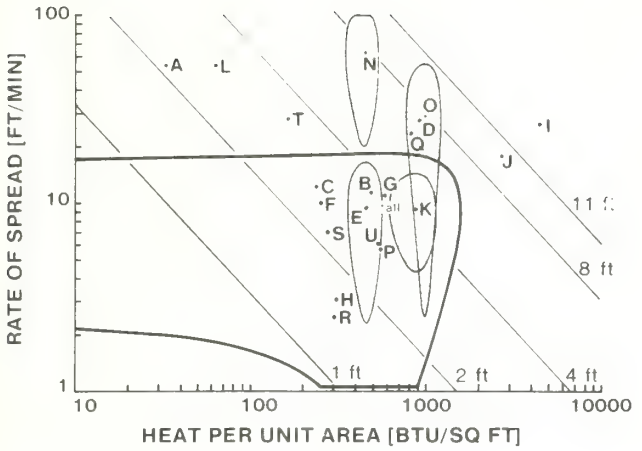

Figure 1.—*Fire characteristics chart displaying the observed behavior mean (*) and a behavior envelope designating one standard deviation (heavy line). Also shown are the means (•) of the predicted potential behavior for each of the 20 NFDRS fuel models, along with envelopes designating one standard deviation for models N, O, E, and K. The diagonal lines represent flame lengths (ft). Logarithmic scale distorts the elliptical envelopes.*

the NFDRS Energy Release Component, the observed rate of spread, heat per unit area, and flame length. Field measurements of flame length and rate of spread were used in figures 1 and 2.

Means

Figure 1 includes the means of the 20 fuel model predictions and the envelope outlining the standard deviations for models E, K, N, and O; numerical values are listed in table 2. Figure 2 shows the predicted average behavior for nine fuel models and five cover type groups. Elliptical envelopes designate one standard deviation for all fires and for models E and K. Figure 2 shows the isolation of fuel model N from the main body of data. Average fire severity, as well as the character of a model, may be inferred from the position of the mean value on the chart. One interesting feature of figure 1 is the clustering of the means of nine fuel models (B, C, E, F, G, K, U, P, and S) between 238 and 873 BTU/ft^2 and between 5.7 and 12.2 ft/min. This cluster surrounds the observed mean for all fires. Two fuel models, H and R, fell below this cluster due to lower rates of spread. The remaining fuel models were scattered over a broad range of BTU per square foot values, but all average predicted rates of spread for these models are higher than the upper boundary of the envelope outlining one standard deviation of observed behavior.

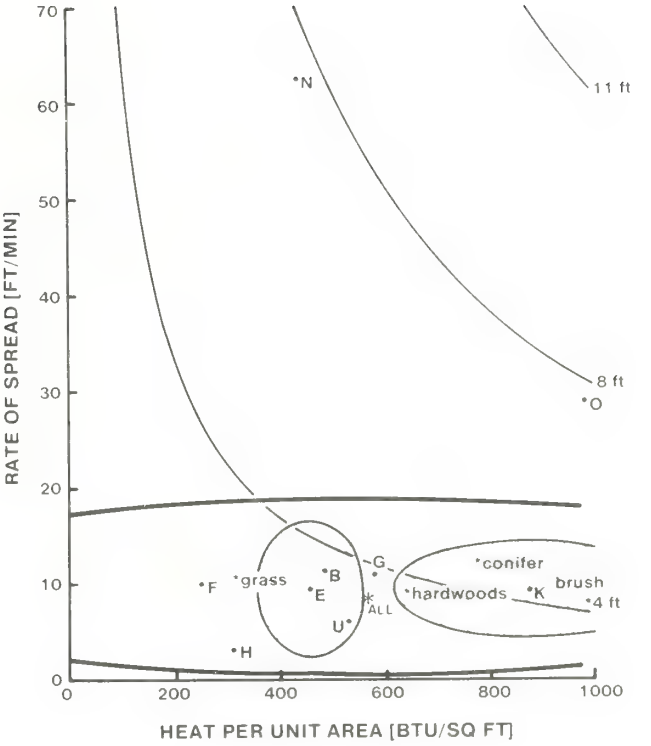

Figure 2.—*Fire characteristics chart displaying observed behavior means (*) for all fires and the following groups: grass, hardwoods, upland conifers, and brush. It also includes means (•) of predicted potential behavior for nine fuel models and behavior envelopes designating one standard deviation for all fires and fuel models E and K. The curved diagonal lines represent flame lengths (ft).*

The mean predicted behavior potentials for fuel models E, F, and K were the only means not significantly different from the all-fires observations ($P < 0.001$). There was no significant difference in mean heat per unit area between models G, P, or U and the mean of all fires ($P < 0.001$); at $P < 0.01$, models B and E are also included (table 2).

Sensitivity

The standard deviation of the observed rate of spread is 9.0 ft/min for the 940 fires (table 2). Six of the 20 fuel models had a notably greater standard deviation than this (A, D, L, N, O, and T); the y-axis elongation was quite evident, for example, in the envelopes for models O and N (fig. 1). These fuel models have a greater response than observed fire behavior. In contrast, 10 fuel models (B, C, E, F, G, I, J, K, Q, and S) had standard deviations in the range $5.0 \leq s \leq 16.8$ or within a factor of two of that observed. These models provide roughly the same

level of resolution as observed fire behavior. Four models (H, P, R, and U) have limited resolution ($s \leq 4.3$) for rate of spread.

The standard deviation for the observed heat per unit area for all fires was 1,007 BTU/ft^2 and only fuel models I and J were within a factor of two. The remaining 18 fuel models had heat per unit area envelopes much smaller than those observed, indicating limited resolution (fig. 1). There are several possible explanations:

1. There are fixed fuel loadings in the models, but this feature is highly variable in nature.
2. Although the model yields a single Burning Index, intensity within individual fires can vary by up to two orders of magnitude (Simard *et al*. 1982).
3. The NFDRS fuel moisture models (which are inputs to the fire behavior models) vary less (have notably lower coefficients of variation) than fuel moisture observed in the field (Simard *et al*. 1984).
4. Flame lengths may be observed less accurately than other information (Johnson 1982).

Predicting Fire Behavior

Although the NFDRS relates to the potential of an initiating fire, our data base contained reports of torching, spotting, or crowning (TSC). With these fires we hoped to identify critical levels of fire danger when such behavior was possible. They were also included in the data base to maintain balance. The fires were identified by adjective classification: smoldering/creeping (22 percent of the total); running, defined as spreading rapidly with a well-defined head (70 percent); and TSC (8 percent). Computations based on the model E Spread Component (see Appendix) indicated that the probability of TSC occurring sometime between initial attack and containment increased at a linear rate as this index scale increased (fig. 3). Even at high index values (SC = 40), however, the probability of TSC behavior was less than 25 percent. In contrast, due to the inherent temporal and spatial variability of fire danger, there was a small but non-zero probability of TSC even at low index values. Running was the most probable behavior, except at very low values of the Spread Component where smoldering or creeping was most probable. On the other hand, there remained a probability that a fire would only smolder or creep at relatively high index values.

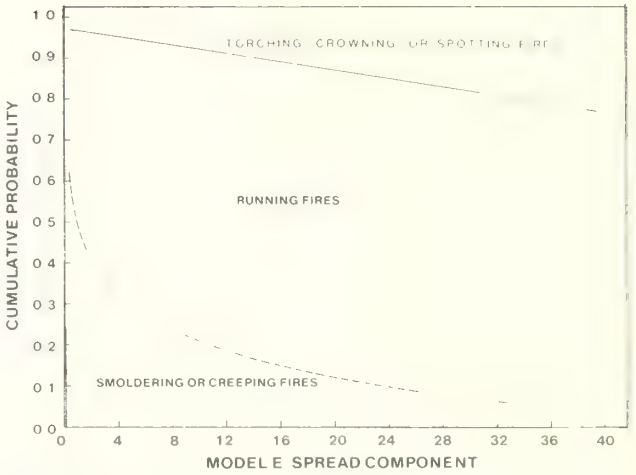

Figure 3.—*Cumulative probability of three classes of worst behavior for 940 fires relative to the model E Spread Component.*

One method of visualizing the relation between observed and predicted fire behavior is with weighted quartile regressions (fig. 4). The lines indicate the values of each index (component) where one-fourth, one-half, and three-fourths of the observations lie below the indicated line. One-half of all observations lie above or below the middle quartile line. An advantage of quartile regression is its resistance to outliers. Note that the ordinary least squares (OLS) solution lies above the middle quartile level due to a few extreme observed values. The divergence of the upper and lower quartile lines indicates that the variance of the observations increases with increasing index values. At the most elementary level, this portrayal shows that the system works—observed values increase with predicted values. It also shows that prediction errors are less

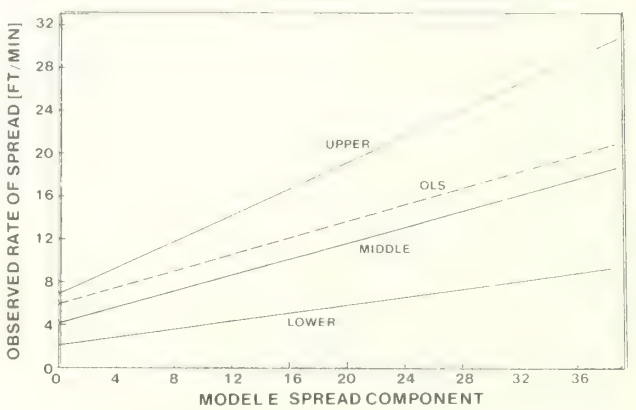

Figure 4.—*Quartile regressions between observed and predicted rates of spread. The OLS line is for the ordinary least squares solution.*

at low index values than at high index values. From a manager's perspective it would, of course, be advantageous if the error situation was reversed.

Figure 5 shows a histogram of standardized residuals for observed rates of spread using the linear regression model. A Gaussian distribution is superimposed to show the departures from normal of the observed data. To test the degree of nonlinearity in the data, we decomposed the error sum of squares into a pure-error component and a lack-of-fit component and then did an F test for linearity (Neter and Wasserman 1974, p. 113). This test showed that the regression function was not linear at the 0.05 level of significance. In addition, we used Bartlett's test for homogeneity of the variance, grouping the observed data by index levels (Neter and Wasserman 1974, p. 509). The observed data groups failed this test, indicating that the increased variance with increased predicted value is significant; therefore, we used a logarithmic transformation on the data. The strongest relations for rate of spread were associated with the form:

$$\hat{Y} = B_0(X^{B_1}) \qquad (2)$$

where

Y = estimated rates of spread (ft/min)
X = NFDRS Spread Component.

The strongest relations for flame length and heat per unit area were associated with the form:

$$\hat{Y} = B_0(B_1^{X}) \qquad (3)$$

where

Y = flame length (ft)
X = NFDRS Burning Index/10.

There are problems in comparing a logarithmic transformation with an untransformed function because the former generates a multiplicative error term and the latter generates an additive error term. Although some authorities advise caution (e.g., Payandeh 1981), others ignore possible implications (e.g., Lewis-Beck 1980). We believe that comparisons of R^2's and standard errors among equation forms should be interpreted with these error sources in mind.

Overall Predictive Accuracy

Results of the regression analysis for all fires are given in table 4. The most striking feature is the low R^2 values relative to those obtained by other investigators who tested fire behavior models in carefully

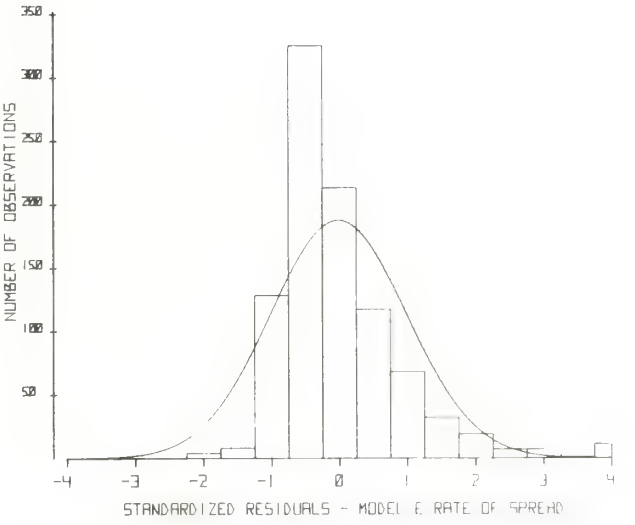

Figure 5.—*Histogram of standardized residuals for rate of spread. A normal distribution is superimposed on the histogram to illustrate the departures from normal.*

controlled experiments (e.g., Andrews 1980, van Wagtendonk and Botti 1984). Values calculated in this study reflect what can be expected when the system is used operationally. Although our study design necessitated treating the observed behavior data as static characteristics, a wildfire is a dynamic process having a wide range of temporal and spatial variability. Although the same applies to prescribed burns, our data generally incorporated only one or two observations of each fire which will, in most cases, differ from the mean value. Low R^2 values will be typical of such data; there are no alternatives if central weather station and wildfire observations are used as the data source.

Table 4 lists the fuel model results for all fires in order of decreasing average R^2. The most accurate combined predictions for all fires were provided by models E and N. Some models scored relatively high for one attribute of fire behavior but low in the other. For example, model G had the second highest R^2 value for rate of spread, but its performance in predicting flame length was unacceptable. Poor performance with the latter could be due to heavy loadings of 100- and 1,000-hour timelag fuels in model G.

For rate of spread, all coefficients differed from the ideal. High intercepts and low slopes indicate that, on the average, all models underpredicted rate of spread at low index values and overpredicted rate of spread at higher values. Model F, for example, has a crossover point at an SC value of about 7. At least two factors are involved in addition to possible model error. The models were designed to predict peak fire

Table 4.--Regression coefficients to transform model-predicted values of potential behavior to observed behavior for all fires

Fuel model[1/]	Rate of spread[2/] R^2	B_0	B_1	Flame lengths[3/] R^2	B_0	B_1	Average R^2
E	0.131	3.12	0.38	0.129	1.12	1.21	0.130
N	.131	1.54	0.38	.129	1.06	1.09	.130
U	.115	3.85	0.35	.129	1.11	1.25	.122
P	.119	3.85	0.37	.123	1.14	1.24	.121
J	.137	1.46	0.55	.097	1.00	1.08	.117
K	.140	2.06	0.55	.092	1.04	1.17	.116
I	.134	1.20	0.54	.091	1.04	1.05	.113
O	.083	3.25	0.24	.133	1.24	1.07	.108
D	.109	2.57	0.32	.103	1.27	1.07	.106
Q	.106	2.87	0.29	.104	1.23	1.08	.105
F	.092	3.79	0.27	.116	1.14	1.27	.104
H	.118	4.87	0.36	.085	1.34	1.32	.102
T	.089	4.05	0.18	.112	1.48	1.10	.101
B	.089	3.73	0.26	.111	1.14	1.18	.100
G	.137	2.59	0.43	.059	1.42	1.10	.093 [4/]
C	.088	4.48	0.20	.105	1.39	1.16	.097
R	.092	5.78	0.25	.102	1.31	1.36	.097
S	.077	1.59	0.16	.099	1.32	1.22	.088
L	.063	4.41	0.12	.074	1.51	1.11	.069
A	.062	4.29	0.13	.066	1.51	1.15	.064

[1/] Listed in order of decreasing combined R^2.

[2/] Rate of spread = $B_0 * (SC)^{B1}$. Standard errors were grouped between 9.0 and 9.2.

[3/] Flame length = $B_0 * B_1^{(BI/10)}$. Standard errors were grouped between 2.0 and 2.1.

[4/] Models below this line are not recommended for general use in the northeastern United States.

behavior (i.e., they have a built-in bias). Thus, regression equations, which predict average behavior, should have slopes less than one. Conversely, in a perfect world there would be no fires at an index value of zero. To the extent that there are and they spread, it is indicative of the spatial variability of fire danger over one weather station's zone of application. There are no negative spread rate observations to balance the positive rates—hence the positive Y-intercept. Results of the overall regression analysis were combined with other criteria to reduce the number of test fuel models from 20 to 12. Remaining tests concentrated on this reduced set.

Predictive Accuracy by Cover Type

The data were stratified by cover type (hardwoods, brush, grass, upland conifer) and the regression analysis redone. Results for the best five models in each cover type are listed in order of decreasing average R^2 in table 5. The most notable feature is an

Table 5.--Ranking of fuel model performance by major cover groups for all seasons and locations (significant at $P < 0.01$)[1/]

Cover group	Fuel model	Rate of spread[2/] R^2	Rate of spread[2/] $S_{y.x}$	Flame length[2/] R^2	Flame length[2/] $S_{y.x}$	Average R^2
			Ft/min		Feet	
Hardwoods (n = 322)	E	0.196	7.3	0.154	1.8	0.175
	N	.191	7.3	.148	1.8	.170
	K	.209	7.1	.128	1.8	.169
	U	.175	7.3	.159	1.8	.167
	G	.209	7.3	.107	1.8	.158
Brush (n = 153)	K	.249	6.6	.238	2.1	.244
	E	.156	6.8	.248	2.1	.202
	N	.164	6.8	.235	2.1	.200
	U	.150	6.9	.231	2.1	.191
	G	.179	6.8	.188	2.1	.184
Grass (n = 317)	E	.133	10.2	.084	1.9	.109
	N	.127	10.3	.084	1.9	.106
	U	.110	10.3	.083	1.9	.097
	D	.116	10.3	.067	1.9	.092
	B	.109	10.4	.071	1.9	.090
Upland conifer (n = 54)	K	.096	14.9	NS[3/]		
	N	.083	15.1	NS		
	F	.075	15.2	NS		
	B	.073	15.2	NS		

[1/] Listed in order of decreasing combined R^2 values within each group.

[2/] The NFDRS Spread Component was used to predict observed rates of spread, and the Burning Index was used to predict flame lengths.

[3/] The regression equation was statistically insignificant at the 0.01 level.

increased R^2 for hardwoods and brush, indicating, as expected, improved accuracy as the cover types are stratified. Model E was best in two cover types (hardwoods and grass) while K was best in the other two (brush and upland conifer). In contrast, model K ranked low in grass cover (presumably due to its lack of live-fuel moisture) and E ranked low in upland conifer (presumably due to limited inclusion of heavier fuels). Models H, O, Q, and T did not rank in the top five for any cover type. The remaining models (B, D, F, G, N, and U) were ranked in the top five in one to four cover types.

In upland conifers, only four models yielded significant spread predictions at $P < 0.01$. Although no model produced significant results at the 0.01 level for flame length, all models were positively correlated with both rate of spread and flame length. Poor correlation may have resulted from the small sample size relative to the other cover types, coupled with the highest average variability of any cover type (table 2). Further, 26 percent of all upland conifer fires behaved erratically (and hence less predictably) compared with 8 percent for all fires.

Robustness

An important factor in judging fuel model performance is the capability to consistently predict potential fire behavior across seasons, locations, and cover types, thereby simplifying the business of fire-danger rating. We calculated the root mean square (RMS) of differences between the all-fires regression curve for each of the three groups and the individual season, location, or cover-type curves. The test,

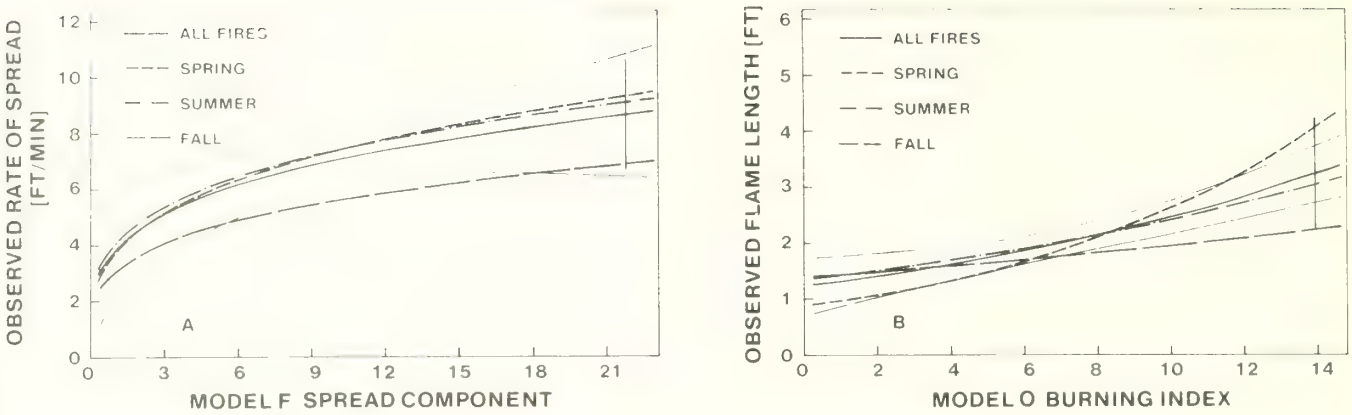

Figure 6.—*(A) Comparison of observed and predicted rates of spread by season using model F Spread Component. The mean plus two standard deviations of the Spread Component is indicated by the vertical line. The heavy solid line denotes the all-fires regression and its confidence limits at (P = 0.01). (B) Comparison of observed and predicted flame lengths by season using model O Burning Index.*

which integrates RMS differences over a range of two standard deviations from the predicted mean (table 2), provides an estimate of each model's robustness.

Models F (fig. 6a) and B produced the lowest RMS (error) value (0.9 ft/min) among seasons for rate of spread, followed closely by model K (1.0) (table 6a). The regression curves for spring and summer were nearly identical, but observed fall values were somewhat lower than those for the other seasons. Model O produced the greatest season-to-season dispersion (RMS = 3.8 ft/min), and models D and E were the next-poorest performers due largely to the departure of the summer season regression (table 6a). Other models (G, H, N, Q, T, and U) performed moderately well from season to season but yielded summer spread rates with steeper slopes than in spring and fall.

Although fuel model O produced the most dispersion with seasonal rates of spread, it, along with B and E, produced the least dispersion (0.3 ft) for seasonal flame lengths (table 6b, fig. 6b). Models G and H failed this test because they did not produce significant fall or summer regression values.

Comparison of variations of the rates of spread by cover type showed that fuel models K (fig. 7a), E, N, and Q yielded the smallest RMS values (0.9 ft/min) (table 6a). Because only models K, N, F, and B produced significant regression equations for upland conifer, data for this cover type were not considered

Table 6a.--A comparative rating of fuel model prediction of rate of spread by various selection criteria[1/]

Criterion	Fuel models											
	B	D	E	F	G	H	K	N	O	Q	T	U
Means (ft/min & BTU/ft^2) (Table 2)	1.7 +	17.7 -	0.2 +	0.4 +	1.3 +	6.5 0	0.3 +	52.7[2/] =	19.4 -	13.9 0	18.2 -	3.5 0
(2) Sensitivity (Table 2)	2.1 +	11.0 0	1.9 +	3.1 0	1.4 +	6.8[3/] 0	4.0 0	33.5 =	17.5 -	7.8 0	12.7 -	4.7 0
(3) Overall Prediction (R^2) (Table 4)	.089 -	.109 0	.131 +	.092 -	.137 +	.118 0	.140 +	.131 +	.083 -	.106 0	.089 -	.115 0
(4) Cover Type Prediction (R^2) (Table 5)	7 -	19 0	31 +	13 0	32 +	24 0	29 +	30 +	11 0	14 0	6 -	18 0
(5) Calibration[5/]	0	0	0	0	+	-	++	+	-	0	=	0
(6) Robustness (ft/min & ft)												
Seasons	.9	2.3[6/]	2.4[6/]	.9	1.6[9/]	1.7	1.0	1.4	3.8[6/]	1.9	1.8	1.6
Cover types[8/]	1.2	1.0	.9	1.0	2.4[9/]	1.3	.9	.9	1.2	.9	1.1	1.3
Locations (States)	1.5	1.4	1.4	1.5	1.3	1.4	1.3	1.3	1.5	1.3	1.5	1.4
Combined robustness	0	-	0	0	-	0	+	+	-	+	-	0
(7) All-criteria unweighted total	0	-2	+4	0	+4	-1	+6	0	-5	+1	-7	0

Table 6b.--A comparative rating of fuel model prediction of flame length or heat per unit area by various selection criteria

	Criterion	Fuel models B	D	E	F	G	H	K	N	O	Q	T	J
(1)	Means (ft/min & BTU/ft^2)	83	337	110	318	12	258	305	128	415[2/]	250	405	38
	(Table 2)	0	-	0	-	+	0	-	0	-	0	-	+
(2)	Sensitivity (Table 2)	807	704	904	894	704	852	747	909	784	779	902	857
		0	+	-	-	+	0	+	-	0	0	-	0
(3)	Overall Prediction (R^2)	0.110	0.103	0.129	0.116	0.059[4/]	0.085	0.092	0.129	0.133	0.104	0.112	0.129
	(Table 4)	0	0	+	0	=	-	0	+	+	0	0	+
(4)	Cover Type Prediction (R^2)	22	10	32	23	4	10	15	26	32	12	20	23
	(Table 5)	0	-	+	0	-	-	0	0	+	0	0	+
(5)	Calibration[5/]	0	+	0	-	0	=	+	++	+	+	0	-
(6)	Robustness (ft/min & ft)												
	Seasons	.3	.4	.3	.4	[7/]	[7/]	.5	.4	.3	.4	.5	.4
	Cover types[8/]	.7	.7	.7	.7	.8	.7	.8	.7	.7	.7	.7	.7
	Locations (States)	.5	.5	.5	.5	.6	.5	.5	.5	.5	.5	.5	.5
	Combined robustness	+	0	+	0	-	-	-	0	+	0	0	0
(7)	All-criteria unweighted total	+1	0	+2	-3	-2	-5	0	+2	+3	+1	-2	+2

[1/] The methods section gives a detailed explanation of each criterion. The first line in each criterion gives numerical values; the second gives a symbolic ranking relative to the other models (++ above, + marginally above, 0 near average or median, - marginally below, = below).

[2/] Models N and O are not recommended for general use unless they are first calibrated.
[3/] Model H had a very limited index range in predicting rate of spread.
[4/] Model G is not recommended for prediction of flame length.
[5/] A single mark (+ or -) was used if one coefficient deviated, and double mark if both deviated.
[6/] Models E and O showed high dispersion for seasonal rates of spread, especially during summer.
[7/] Models G and H did not produce significant results for either summer or fall flame lengths.
[8/] Only models B, F, K, and N produced significant results for rates of spread with conifer fires; no models gave significant results for conifer flame lengths.

[9/] Model G is not recommended for brush fires.

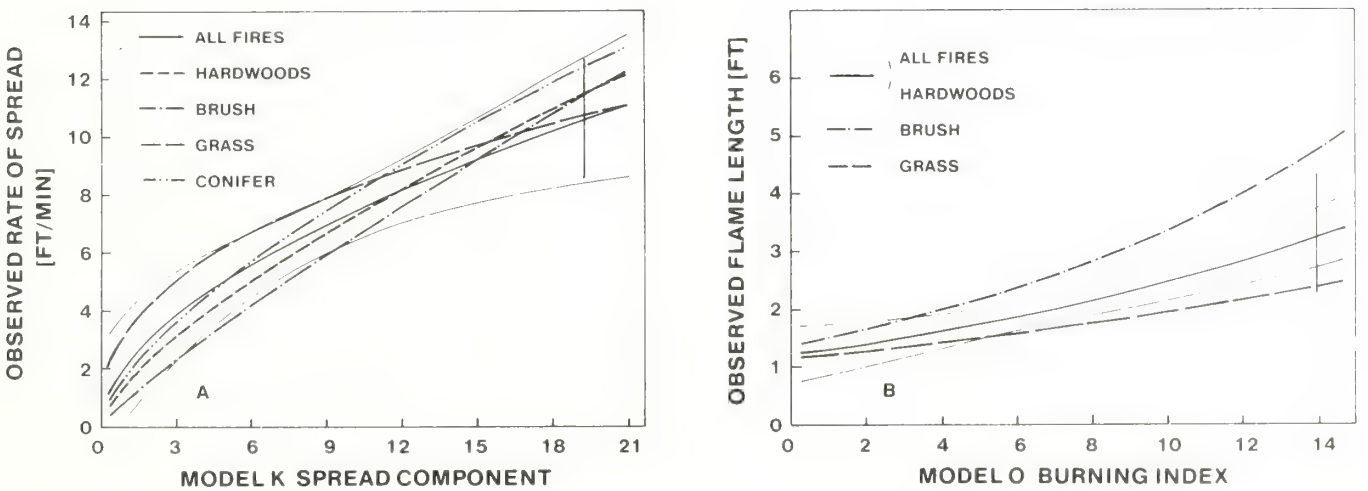

Figure 7.—*(A) Comparison of observed and predicted rates of spread by cover type using model K Spread Component. (B) Comparison of observed and predicted flame lengths by cover types using model O Burning Index. The conifer group did not produce significant results. The regression line representing hardwoods is indistinguishable from all fires.*

in the analysis. The other models yielded RMS values ranging from 1.0 ft/min for models D and F to 2.4 ft/min for model G. For flame length, no fuel models yielded significant regression results for upland conifer. A recomputation of the data using the other cover types showed little difference in RMS values among models (0.7 to 0.8 ft) (table 6b). Regression curves for fuel model O are shown in figure 7b.

Analysis of the data by location showed little dispersion difference for either rate of spread or flame length (RMS = 1.3 to 1.5 ft/min and 0.5 to 0.6 ft, respectively) (fig. 8). The small differences in flame length by location (table 6b) appeared related to differences in cover type and, therefore, the results indicated that location is not a significant factor in evaluating fire-danger rating in much of northeastern United States.

Rating the Models

The 12 models were rated for rate of spread and flame length predictions by six criteria using the following method (table 6). As a first approximation, if the value for a model was within one standard deviation of the mean value for all tested models, it was assigned a 0; if the value was close to or greater than one standard deviation away, it was assigned a + or −, depending on which direction was superior; if close or greater than two standard deviations away, it received a ++ or =.

For criterion (1), we calculated the difference between the model mean and observed mean, and used the standard deviations of the differences to rate the models. The smaller the difference, the better its performance. Thus, for rate of spread, models B, E, F, G, and K ranked higher than the others; D, O, and T ranked lower, and N ranked much lower.

For criterion (2), we calculated the difference between the standard deviation of observed fire behavior and the standard deviation of model predictions. Based on the standard deviation of the differences for rate of spread, B, E, and G ranked notably above average; N, O, and T ranked lower to much lower.

For criterion (3), we calculated the coefficient of determination (R^2) of observed fire behavior for all fires. For rate of spread, four models (E, G, K, and N) were above average and four (B, F, O, and T) were lower.

For criterion (4) we determined the relative rank (first, second, and so forth) of each model's R^2 value for each of three cover types (hardwoods, brush, and grass). Each rank was assigned a point value (first = 12, second = 11, etc.). Points were summed for each model across the three cover types for rate of spread and flame length. For example, model E accumulated 31 points in rate of spread based on the third-highest R^2 value for hardwoods (10 points, table 5), fourth-highest value for brush (9), and highest for grass (12). Upland conifer cover was not considered due to the limited number of significant regressions.

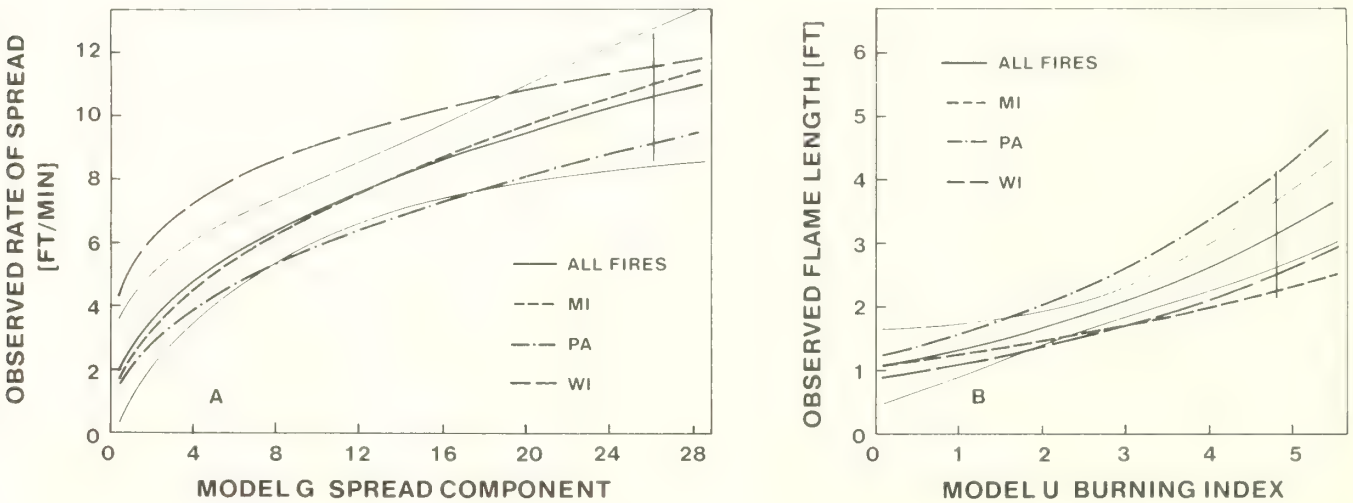

Figure 8.—*(A) Comparison of observed and predicted rates of spread by location using model G Spread Component. (B) Comparison of observed and predicted flame lengths by location using model U Burning Index.*

For criterion (5), the ideal regression coefficients should be $B_0 = 0$ and $B_1 = 1$. We determined the standard deviation of the coefficients and assigned a + or − to each model depending on the closeness of the coefficients to the ideal. A double sign indicates that both coefficients were notably different from average. For rate of spread, both coefficients were better than average for model K. For flame length, both coefficients were poorer than average for model H. Models G and T had compensating differences for flame length.

For criterion (6), we summed the three RMS values for each model and used the standard deviation of the sums to assign a + or −. For rate of spread, three models (K, N, and Q) were superior and four (D, G, O, and T) were inferior.

Various models produced atypical situations for some criteria, and these are noted on the bottom of table 6. At times these situations caused distributions that were decidedly non-normal; consequently, the ratings were adjusted. The best example is the model N value of 52.7 ft/min in criterion (1). In this case model N was assigned a = and deleted from the group. The remaining 11 models were reevaluated without model N.

Composite Rating

If managers have one or two fuel complexes or specific uses, the best NFDRS model choices are indicated by the ratings for individual criteria. If a general-purpose model is needed, however, individual ratings must be combined. One way to combine individual ratings is to simply sum the +'s and −'s. Such a scheme rewards or penalizes only models that were notably better or worse than the average. It emphasizes the distinction between models that passed or failed a test. In contrast, a rank-sum approach ignores the magnitude of differences between test results. For each criterion, we ranked the models from first to last, as we did for the robustness combination, and then calculated the sum of the ranks for all criteria. By using both methods to combine the rankings, we hoped to avoid possible bias associated with the arbitrary choice of one method.

Both of the preceding schemes assumed that all criteria were equally important. In fact, the relative importance placed on each criterion will vary with a manager's needs depending on the final use of the results. We developed a simple weighting scheme for each criterion and used it, along with an unweighted combination, to determine whether or not weights would affect the final ordering of the models. The least weight (w = 1) was assigned to the mean and calibration criteria (1 and 5), because a user can compensate for them. Average weight (w = 2) was assigned to the sensitivity and robustness criteria (2 and 6), and the greatest weight (w = 3) to prediction accuracy criteria (3 and 4).

Each of the four combinations (sign, rank, unweighted, and weighted) was calibrated so that the highest possible score equaled 100 and the lowest equaled zero. Thus, the final rankings indicated not only how well each model performed relative to every other model, but also how well each model performed in an absolute sense. Finally, the four combinations were aggregated into a composite rating by adding the scores and dividing by four (table 7). The calibration ensured that each combination contributed equally to the composite rating. We also considered balance, downgrading models (G, K, and O by 5 points) that did well for one behavior characteristic but poorly for the other. Table 7 also classes the models into five performance groups. In general, models within a higher group did better than models in the next lower group, but differences between closely rated models were slight.

Although the combination schemes were somewhat arbitrarily chosen, the four different procedures yielded remarkably similar results. Eleven of

Table 7.--Relative overall rating of NFDRS models in the northeastern United States[1/]

Fuel model	Rating
E	79
K	67
N[2/]	64
U	62
B	54
Q	53
G[2/]	51
F	46
D	44
O	41
H	33
T	19

[1/] Listed in order of estimated overall performance. Differences between models within a group are not considered significant. Ratings are on a 100-point scale.

[2/] These models are conditionally acceptable. The major deficiency noted in table 6 (=) must be either compensated for or be unimportant in the use to which the model is put.

the 12 models had a range of three or less between the highest and lowest rank across all four combinations. Thus, the composite rating is not dependent on the characteristics of any single procedure. We therefore conclude that the composite ranking is generic—any reasonable scheme would yield much the same outcome.

A slightly different method of ranking was used by Haines *et al.* 1985 (see their table 5). They calculated a ratio rather than a difference for criterion (2), and also rated only 9 rather than 12 fuel models. These variations in procedures resulted in some changes in final rankings from those shown in table 7. For example, models K and E interchanged first and second positions.

Model E (overall score = 79) is alone in the first group (table 7); it was first in every ranking combination. It was average or better in 11 of the 12 tests (best or second best in 5 tests). Only flame length sensitivity was below average. For most areas in the northeastern United States, model E appears to be the best general-purpose model because it is suited to a wide variety of conditions and applications. Upland conifer forests are a notable exception to model E's overall superiority.

The second group includes three models (K, N, and U). Model K was the best overall spread rate predictor (it was first or second in four of six tests). It was only average at predicting energy release (causing it to be downgraded slightly). Model K was best in brush and upland conifer. The lack of live fuel loading in model K may account for its good performance in the latter case. Its second-highest overall rating, however, appears counterintuitive, but there is a possible explanation. When fuels are green in the Northeast, their moisture content may be so high as to overwhelm other environmental conditions and preclude wildfire occurrence. In fact, in the Northeast observed live fuel moisture typically exceeds that allowed by the NFDRS models by factors ranging from 1.5 to 4 times (Loomis *et al.* 1979, Loomis and Blank 1981). In this situation, living vegetation may be like a switch that turns fires on and off rather than a heat sink that reduces spread rates and intensity. Our behavior data came only from days on which fires occurred and grew to reportable dimensions—days on which high-moisture-content fuels would have to have been cured or nearly so to permit fire spread. Thus, although live-fuel moisture certainly plays a key role in fire behavior, our results suggest that the role is not well defined in this region.

The high intercorrelation between models I, J, and K ($R^2 = 0.99$ in all cases) permits us to extrapolate from model K to I and J. Tables 2 and 4 present the data needed for four of the six tests for models I and J (means, sensitivity, overall predictive accuracy, and calibration). Based on these four criteria, model I would have been marginally poorer than K, and model J would have been marginally better. Greater average spread rates would require calibration prior to use. In essence, if models I or J were desirable for some purpose, they could be substituted for K with confidence.

Although fuel model N ranked within the second group in table 7, it was inconsistent. It was the only model to appear in the top five places in all four fuel groups (table 5). It was best or second best only in the two less important calibration tests, and it was the worst model in three tests. Model N showed significantly substandard performance in the rate-of-spread means and sensitivity tests (table 6a). This problem would have to be either overcome or of little consequence to the user.

Although model U didn't quite reach the rating of models E or K, it is also a good general-purpose model. It appeared in the top five places in three of the four cover groups (table 5). Interestingly, the exception was upland conifer (model U was intended to represent long-needled pine stands—see Methods section). Model U was one of only two models that was below average in only one test (flame length calibration), and it was above average in 3 of 12 tests. In other words, model U is not outstanding, but it appears generally reliable. Because models U and P appear similar in construction and are highly intercorrelated (SC = 0.99 and ERC = 0.92, table 3), P should perform about as well as U.

The next two groups in table 7 include models with lower overall performance. Model B's performance is most like that of U. The former was below model U in five tests, better in four, and tied in three. Like U, model B was second in just one test and it was one of the top fuel models in two fuel groups. Its overall predictive accuracy was next to last in the list of acceptable models (table 4). In general, model B had no outstanding attributes, but few negative ones—in other words, its performance was average. It is most likely that one of the previously recommended models would be superior for most Northeastern applications.

As with model U, Q was a steady performer. It was the only model that was average (10 times) or above (twice) in every test. It never ranked better than fourth nor worse than ninth, and was the best-balanced model tested (spread rate and flame lengths). In summary, model Q can also be classed as

average. Given the superior performance of other models, its use should be justified using criteria other than those employed in this study.

Model G's performance might be best classified as a paradox (even more so than with model N). Model G ranked first or second in 5 of 12 tests but 11th or worse four times. It either worked very well or failed miserably! Its predictive accuracy for energy release is considered unacceptable (table 4), yet it was first in the flame length mean and sensitivity tests. It was the second-best spread rate predictor (first or second in three of six tests), but it did poorly (11th) in robustness. Model G was one of the top five models in two fuel types. Although model G cannot be recommended as a general-purpose model, it may be useful as a "specialty" spread rate predictor.

Models D and F both ranked below average more often than above. Both were first through third in just one test; both were never ranked worse than 10th. Both were in the top five models in just one cover type. Both models ranked below average for general use with no notable "specialty" purposes.

Model O was the worst-balanced model tested. It was the best flame length model (first through third in four of six tests) but the worst (of the models considered so far) in rate of spread (10th or worse in every test). Clearly, model O would be a poor general-purpose model but a good energy release "specialty" model.

The last group includes the only two models (H and T) that ranked average or below average in every test. With 10 better models to choose from, it is hard to imagine a general purpose for which these two models would be needed. Models H and T, along with the previously deleted models (A, C, L, R, and S), are not recommended for general use in the Northeast.

Fuel Model Composition-Performance

These data provided an opportunity to postulate causal mechanisms. We considered the relative performance of the 20 fuel models as observational data, and could then conceptually equate fuel model parameters (Bradshaw *et al*. 1983) to experimental treatments. Our task was to learn something about how the NFDRS, with its 114 equations and uncounted assumptions, relates fuel model parameters to fire behavior. The task was complicated by the fact that there are only 20 models to compare when drawing conclusions concerning 12 interrelated treatments with random combinations of treatment levels.[2]

One simple relationship provided some insights. The four lowest ranked models, in terms of overall predictive accuracy (A, L, R, and S—table 4), have 10-hour fuel loadings of 0.5 tons/acre or less (Bradshaw *et al*. 1983, p. 38). Two other models with the same loadings (D and T) finished 9th and 12th, respectively, in our ranking system. Models A, L, R, and S also have extremely light 1-hour loadings (0.5 tons/acre or less), but models D and T have 1-hour loadings of 2.0 and 1.0 tons/acre (within the range of higher ranked models). We therefore suspect that the 1-hour loading is not a limiting factor in poor model performance. We further infer that in the Northeast, light 10-hour loadings (0.5 tons/acre) result in poor-performance fire behavior models. Extrapolation, however, is less certain. Models C and H, for example, yielded the next-poorest predictions and have 10-hour fuel loadings of only 1.0 tons/acre. Model P, on the other hand, also has 1.0 tons/acre of 10-hour fuels and we assume (by association with model U) that it should be a reasonably good predictor.

Four of five models (A, F, L, and T) with a 15 percent moisture of extinction (ME) ranked eighth or lower; B also has a 15 percent ME. It was 14th in terms of predictive accuracy (table 4), but it finished 5th overall based on all tests. Possibly 4 tons/acre of 10-hour fuels helped overcome the 15 percent ME in model B. In general, a 15 percent ME may preclude optimum model performance in the Northeast. Note that the two poorest performance models (A and L) have no 10-hour fuels coupled with a 15 percent ME.

Again, extrapolation is problematic. Models C, H, and U have ME's of 20 percent. Models C and H were not high performers but U was fourth highest. Note, however, that models C and H have 10-hour loadings of 1.0 tons/acre. Perhaps two marginal factors combined to yield poor performance (model P has an ME of 30 percent).

In general, poor model performance appears to be associated with low ME's (20%≤) and low 10-hour fuel loadings (1.0 tons/acre). These results agree with the findings of Simard *et al*. (1984), who found that 10-hour fuel moisture was the best predictor of observed fine fuel moisture. Low 10-hour loadings

[2]*Nineteen parameters are used to define each fuel model, but six are constant and, therefore, do not directly contribute to observed model differences; one only affects a component not tested here.*

reduce the contribution of the 10-hour moisture values to the NFDRS-calculated average fine fuel moisture. They also found that observed moistures were much higher than those calculated by the NFDRS. Hence, a low ME should lead to poor fuel model performance.

In contrast to poor fuel model performance, it is not as easy to identify fuel parameters associated with high model performance. Table 8 lists 10 parameters associated with three of the higher ranked rate of spread predictors (K, E, and G) and energy release predictors (O, E, and U). Insight into a solution requires finding common parameter characteristics within each of the two groups of fuel models. Unique results provide important clues to the adequacy of our methods. For example, model E appears in both groups; thus E should have one or more parameters in common with each group, but there must be at least two groups of parameters—one for rate of spread and one for energy release. Furthermore, model G was a highly ranked rate of spread model but a poor predictor of energy release. Model K was similar but to a lesser extent (best for rate of spread, average for energy release). Model O compliments these results (low for rate of spread, best for energy release). Any favorable characteristics for these unbalanced models on one side of the ledger should be absent on the other.

The model ranking results should provide clear, unambiguous tests, but an analysis of the data in table 8 provides no easy answers. Only one firm conclusion emerges: Resolving the question of what generates good model performance is not likely to be found by simply examining fuel model parameters. Rather, more detailed experiments will have to be made in which the NFDRS is disaggregated below the system level and multiple parameter/model interactions are examined. This is well beyond the scope of the present paper.

Comparative Performances of Fire Activity Predictors

The second step in our validation study compared the performances of various meteorological elements, fuel moisture models, and fire danger indices listed in the Appendix. The predictors of behavior potential that did not yield regression values significant at $P < 0.01$ were eliminated, leaving a shortened list categorized by three groups: meteorological elements, fuel moisture models, and fire-danger indices (table 9). All predictors were compared with observed behavior using functions (2), (3), and:

$$Y = B_0 + B_1X \qquad (4)$$

The functional forms listed in table 8 gave the highest R^2 values for each predictor. In all cases standard errors were similar within groups and were higher for rate of spread than for flame length.

Among the meteorological elements, PRECIP and RH produced very low regression values and by themselves appeared to be poor predictors of rate of spread and flame length. Windspeed produced somewhat better results with rate of spread.

The fuel moisture models behaved as expected, yielding comparatively low R^2 values, because they do not incorporate windspeed. The FFM in the 1964-FDRS was the only fuel moisture model that gave statistically significant results when compared with flame length.

The NFDRS values for model E in table 9 are the same as those listed in table 4. Other fuel model values in table 4 can also be compared with fire-danger indices listed in table 9. The fire-danger indices from the Canadian system (ISI, FWI) yielded lower R^2 values than most NFDRS fuel models; the FWI was an especially poor predictor of flame

Table 8.--Fuel model parameters for three higher ranked rate of spread and energy release predictors[1/]

Predictor	Parameter									
	Fuel load						1-hr SA/V[2/]	Heat content	ME	Fuelbed depth
	1-hr	10-hr	100-hr	1,000-hr	Woody	Herbaceous				
	Tons/acre						(Ft^{-1})	BTU/lb	Percent	Ft
Rate of spread										
Model K	2.5	2.5	2.0	2.5	--	--	1,500	8,000	25	0.4
Model E	1.5	2.0	.25	--	0.5	0.5	2,000	8,000	25	.6
Model G	2.5	2.0	5.0	12.0	.5	.5	2,000	8,000	25	1.0
Energy release										
Model O	2.0	3.0	3.0	2.0	7.0	--	1,500	9,000	30	4.0
Model E	1.5	2.0	.25	--	.5	.5	2,000	8,000	25	.6
Model U	1.5	1.5	1.0	--	.5	.5	1,750	8,000	20	.5

[1/] Includes only those parameters that vary among the highest ranked models.
[2/] Ratio of surface area to volume.

Table 9.--Comparative performance of components[1/] of fire-danger rating systems based on predictions of rate of spread and flame length using windspeeds and slopes from fire sites

Fire activity predictor	Rate of spread			Flame length		
	R^2	$S_{y \cdot x}$	Mathematical function	R^2	$S_{y \cdot x}$	Mathematical function
Meteorological elements						
WS	0.069	9.3	(3)	NS	NS	
RH	.032	9.4	(3)	0.022	2.2	(3)
Fuel moisture models						
FFM	.022	9.5	(3)	.052	2.2	(3)
FM_1	.031	9.4	(3)	NS	NS	
FFMC	.033	9.4	(3)	NS	NS	
Fire-danger indices						
SC & BI (Model E)	.131	9.1	(2)	.129	2.1	(3)
TSI	.105	9.2	(2)	.128	2.1	(3)
FFSI	.097	9.2	(2)	.134	2.1	(3)
ISI	.094	9.2	(2)	.105	2.1	(4)
FLI	.083	9.3	(2)	.110	2.1	(4)
FWI	.073	9.3	(3)	.034	2.1	(4)

[1/] Only those predictors with significant regression statistics are included.

length. These results may reflect the fact that the Canadian system was designed for a specific fuel type—jack pine and lodgepole pine (Appendix)—and our data base included only 6 percent upland conifers (table 1). The fire-danger indices from the 1964-FDRS, the TSI, and the FFSI produced similar results. The FFSI gave the highest R^2 value for flame length of any index tested, although the index was not significantly better.

No index that measures drought or long-term drying produced significant results. This included the longer timelag fuel moistures in the NFDRS, the DMC, ADMC, and the DC in the Canadian system, the BUI in the 1964-FDRS, and the KBDI.

SUMMARY AND CONCLUSIONS

We compared the performance of 20 NFDRS fuel models in predicting potential rate of spread and flame length for 940 wildfires in the Northeast, and evaluated the system as it is used operationally. Standard weather station data were used as inputs, and supplemental fire behavior data were compared with system outputs. Model E was the best general-purpose model; models K, N, and U ranked slightly lower. Other models, such as G and O, performed well in specific areas, but were substandard in others. In selecting a model, a manager will have to decide which fuels or test criteria are most important and choose the fuel model on that basis.

Our results confirmed the general belief that no single fuel model is best for all purposes. In fact, one model (O) was best at predicting flame length but second worst at predicting rate of spread. We also found that fuel model performance did not necessarily reflect the qualitative descriptions that are often used for model selection. For example, fuel models A and L were among the poorest predictors of fire behavior in grass. The performance of some models was also counterintuitive. For example, the second-best overall fuel model (K) does not include live-fuel moisture. Such anomalies indicate that although we may understand some fire behavior processes, we are weak in understanding how they all interact in the complex situation of fire-danger rating. Our results suggest that poor fuel model performance in the Northeast may be related to low 10-hour fuel loading (1.0 ton/acre $\leq$) and low moisture of extinction (20%$\leq$).

Since the release of the 1978 revision of the NFDRS, some Northeastern fire managers have questioned the applicability of any of the 20 fuel models to their specific areas and suggested that

they need additional models. Given the spatial coverage of fuel models in figure 1, it is difficult to see what other range of activity values might be included. If the heat per unit area falls much below 100 BTU/ft^2, fires will not generate enough energy to maintain themselves. Fires burning at an intensity much above 1,000 BTU/ft^2 usually display erratic characteristics and, by definition, the NFDRS is not applicable in that situation. Nine fuel models predicted higher average rates of spread than occurred in two-thirds (one standard deviation) of observed fires. If anything, the models display more redundancy and overlap than gaps on the fire characteristics chart. We suspect that many managers really need a fire behavior fuel model rather than a fire-danger planning model.

An examination of indices from present and past fire-danger rating systems, fuel moisture models, and drought codes compared their capability to predict the potential of two measures of fire behavior. Eleven NFDRS fuel models yielded comparatively higher R^2's than any other index tested for rate of spread. The Fine Fuel Spread Indices from the 1964-FDRS produced about the same R^2 values for flame length prediction as the three best NFDRS fuel models. Thus, over the past two decades we appear to have improved our ability to predict rate of spread, but have made little progress in predicting energy release rate.

Our results indicate that, although the NFDRS works in the Northeast, there are overall performance problems. In large part, this is due to the inherent temporal and spatial variability of fire behavior. Given such variability, however, one may ask: How good can any practical system be? At what point does system complexity exceed the natural and operational limits of resolution? Only by studying fire-danger rating from the perspective of the system as a whole can such questions be resolved. In taking such an approach, we attempted to shed new light on perhaps the oldest topic in wildland fire research—yet, a topic which remains unresolved after 75 years of study.

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APPENDIX

FIRE-DANGER RATING SYSTEMS

The following gives a brief overview of the various systems discussed in this paper and defines the terms used. Although the systems are designed to categorize a number of physical features, the following discussion concentrates only on the components that contribute to the examined predictors of potential fire behavior. Complete discussions are available in the original publications documenting each system.

The 1978 National Fire-Danger Rating System (NFDRS)

Deeming *et al.* (1977) state that this system relates only to an initiating fire—i.e., a fire that does not behave erratically. The NFDRS addresses only those aspects of fire activity involving occurrence and behavior. Aspects of containment such as accessibility, soil condition, and resistance to line construction must be evaluated by other means.

Ratings are relative, not absolute. Indices and their components were designed to be linearly related to the fire problem. This design specified that when the value of the component or index doubled, the rated activity also doubled. The basic observations that implement the system are taken once a day when fire danger is normally the highest, in the open, at midslope, on southerly or westerly exposures. The system, therefore, evaluates the worst conditions of fire danger that might occur on a rating area during the rating period.

The NFDRS begins by estimating four classes of dead and two classes of live fuel moisture (FM): 1-, 10-, 100-, and 1,000-hour timelag, woody, and herbaceous. These moistures are combined with windspeed to produce three fire behavior components: ignition (IC), spread (SC), and energy release (ERC). The SC and the ERC combine to produce a burning index (BI).

The FM_1 (1-hour timelag fuel moisture) estimates the moisture content of the fine fuels. These fuels consist of dead herbaceous plants and roundwood less than 1/4 inch in diameter. This also includes the uppermost layer of litter on the forest floor.

The FM_{10} (10-hour timelag fuel moisture) estimates the moisture content of dead fuels consisting of roundwood 1/4 to 1 inch in diameter and, very roughly, the layer of litter extending from just below the surface to 3/4 inch below the surface.

The FM_{100} (100-hour timelag fuel moisture) estimates the moisture content of dead fuels consisting of roundwood of 1 to 3 inches in diameter and the forest floor from 3/4 inch below the surface to 4 inches below the surface.

The FM_{1000} (1,000-hour timelag fuel moisture) estimates the moisture content of dead fuels consisting of roundwood 3 to 8 inches in diameter and the forest floor more than 4 inches below the surface.

The IC gives a rating of the probability that a firebrand will ignite wildland fuels, causing a fire that requires suppression action.

The SC is a rating of the forward rate of spread of a head fire and is scaled directly to rate of spread in feet per minute.

The ERC yields a rating related to the available energy per unit area within the flaming front at the head of a fire. It is equal to the heat per unit area (BTU/ft^2) divided by 25.

The BI gives a rating related to the contribution of fire behavior to the effort of containing a fire. It is equal to 10 × flame length (ft).

The Canadian Forest Fire Weather Index (FWI)

According to Van Wagner (1974), the designers' major goal was a fire-danger index that would yield uniform results across Canada and be based on once-a-day weather observations. The system is designed for a specific fuel type—jack or lodgepole pine.

This empirically derived system consists of six components. There are three moisture codes: fine fuel moisture (FFMC), duff moisture (DMC), and drought (DC). These moisture codes are combined and windspeed is added to form two intermediate components—the initial spread index (ISI) and the adjusted duff moisture code (ADMC)—and a final product, the fire weather index (FWI). This Canadian system and the system used in Australia appear to be similar (Reifsnyder 1978). The FWI is also used operationally in New Zealand.

The FFMC represents the moisture content of litter and other cured fine fuels in a forest stand in a layer of about 0.05 lb/ft^2 dry weight.

The DMC represents the moisture content of loosely compacted, decomposing organic matter 2 to 4 inches deep and weighing about 1 lb/ft^2 when dry.

The DC represents a deep layer of compact organic matter weighing about 10 lb/ft^2 when dry.

The ISI combines wind and the FFMC to represent rate of spread, without the influence of variable quantities of fuel.

The ADMC combines the DMC and the DC to represent the total fuel available to the spreading fire.

The FWI combines the ISI and the ADMC to represent the intensity of the spreading fire as energy output rate per unit length of fire front.

1964-National Fire-Danger Rating System (1964-FDRS)

The 1964-FDRS was the first attempt at designing a national system, but this system did not progress beyond the spread phase (USDA Forest Service 1964). It estimates fine-fuel moisture (FFM) and combines it with windspeed to yield a Fine Fuel Spread Index (FFSI). Another component of the system estimates a Timber Spread Index (TSI) and a slow-response estimate of drying called a Buildup Index (BUI).

The FFM uses the stage of the herbaceous vegetation along with the ambient temperature and relative humidity to produce an analog of moisture in fine fuels.

The FFSI provides a measure of the relative rate of forward movement of surface fires in light fuels.

The TSI provides a measure of the relative rate of forward movement of surface fires in heavier fuels.

The BUI provides a measure of the progressive drying of fuels and, according to the system designers, is related to the moisture content of 10-day timelag fuels. It appears to be more representative of fuels having a 5-day timelag constant (Haines *et al*. 1976).

The Keetch-Byram Drought Index (KBDI)

Fire-danger rating systems in the United States have never used a slow-response drought index. Keetch and Byram (1968) developed this index to provide fire management with a scale of reference for estimating deep-drying conditions in areas where such information was needed for fire suppression.

The KBDI uses daily maximum temperatures and 24-hour precipitation amounts to estimate the precipitation necessary to return the soil to full field capacity.

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Fire-danger rating and observed wildfire behavior in the Northeastern United States. Res. Pap. NC-274. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 23 p.

Compares the 1978 National Fire-Danger Rating System and its 20 fuel models, along with other danger rating systems, with observed fire behavior and rates the strengths and weaknesses of models and systems.

KEY WORDS: Fuel models, flame length, rate of spread.

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Research Paper **NC-275**

Biology and Control of Scleroderris Canker in North America

Darroll D. Skilling, Bruce Schneider, and Donald Fasking

Inset, front cover: *Branch dieback on red pine caused by* G. abietina. *This symptom is usually most ovbious in early spring.*

Front cover: *Severe mortality in pole-size red pine in New York caused by the European strain of* G. abietina.

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CONTENTS

	Page
Taxonomy	2
Distribution of *G. abietina*	2
Host Range	4
Materials and Methods	4
Results	4
Discussion and Conclusion	6
Short Distance Spore Dissemination	6
Materials and Methods	6
Results and Discussion	7
Long Distance Spore Dissemination	7
Materials and Methods	7
Results and Discussion	8
Infection Biology	8
Spread Within Stands	11
Materials and Methods	11
Results and Discussion	11
Variation of Fungus Isolates	13
Control	14
Silvicultural	14
Legal	14
Genetic	14
Chemical	15
Literature Cited	16

BIOLOGY AND CONTROL OF SCLERODERRIS CANKER IN NORTH AMERICA

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During the 1930's when the Civilian Conservation Corps and the Work Projects Administration were involved in large-scale tree planting programs, pines were regarded as the most desirable species for reforestation. In the Lake States, red pine (*Pinus resinosa* Ait.) and jack pine (*P. banksiana* Lamb.) were the primary species planted. In the New England States the major species were red and eastern white pine (*P. strobus* L.). As a result of these planting programs, today we have 1.4 million hectares of red, jack, and eastern white pine in the Lake States and 1.3 million hectares of these three species in the New England States. These pine stands are potentially one of our most valuable conifer resources and any disease problem that threatens them would have serious economic implications. Scleroderris canker, caused by the fungus *Gremmeniella abietina* (Lagerb.) Morelet (= *Ascocalyx abietina* (Naumov) Schlaepfer-Bernhard), poses such a threat. In addition, the disease is also a possible threat to the 2.3 million hectares of ponderosa pine (*P. ponderosa* Laws.) and the 3.1 million hectares of lodgepole pine (*P. contorta* Dougl.) currently growing in the northern Rocky Mountain region.[1]

[1]*Forest statistics of the U.S., 1977 Review Draft. USDA Forest Service, North Central Forest Experiment Station.*

Two strains of the fungus, the North American and the European, are known in North America. The North American strain was not identified in the United States until 1964 (Ohman 1966), but evidence indicates that the disease had been present in Lake States stands since at least 1950. The disease, as observed from 1950 to 1964, was a problem of nurseries and young plantations. The causal fungus was spread on infected nursery stock throughout the northern Lake States and by 1965 was well established in National Forest plantations of red and jack pine in Michigan and Wisconsin. Approximately two-thirds of these plantations were infected with Scleroderris canker and losses from the disease were estimated at approximately 40 percent of the seedlings planted (Skilling and Cordell 1966). As serious as this damage was, trees that survived and reached 2 m or more in height were able to "outgrow" the disease; thus it was only considered a problem in nurseries and juvenile stands. The Forest Pathology Project of the North Central Forest Experiment Station (NCFES), developed a nursery fungicide spray program that now protects millions of conifer seedlings from infections each year. Since 1972 nursery managers have been producing healthy nursery stock for field planting. This has reduced the incidence of Scleroderris canker to manageable levels in northern Lake States pine plantations.

In 1975 Scleroderris canker was reported on red and Scotch pine (*P. sylvestris* L.) in New York State (Setliff *et al.* 1975). The symptoms observed, however, did not match those previously seen in the Lake States. Rather than infecting only young trees, Scleroderris canker killed trees of all ages from young seedlings to mature saw log trees. By 1977 Scleroderris canker was present in a 14,000-hectare area. In many 30- to 40-year-old red pine stands mortality was more than 90 percent and the remaining trees were heavily infected and had poor vigor. The disease showed the potential to move across northern New York State and kill large numbers of trees in all pine plantations infected (Miller and O'Brien 1977). In 1976 research by the NCFES and the Canadian Forestry Service determined that the fungus present in New York was different from that found in the Lake States but was serologically identical to fungus isolates found in Europe (Dorworth *et al.* 1977). The fungus was named the European strain of *Gremmeniella abietina* to distinguish it from the North American strain previously studied.

In 1976, research was begun on the European strain of Scleroderris canker in New York. Many of the problems encountered in this research were similar to those encountered with the North American strain. Therefore research work with the North American strain was used as a guide during the early research on the European strain.

The results of the research program in New York were summarized at an international symposium on Scleroderris canker in conifers held at Syracuse, New York, in June 1983. The proceedings of this symposium contains 40 papers on Scleroderris canker and represents the current status of the world's knowledge on this disease (Manion 1984).

TAXONOMY

The scientific nomenclature for the fungus causing Scleroderris canker has gone through a long series of changes dating back to the 1800's. When Van Vloten and Gremmen (1953) placed the fungus in the genus *Scleroderris*, it appeared the matter was settled, but discussion among taxonomists continued. Morelet (1969) developed the new genus *Gremmeniella* solely to accommodate this fungus, which became *G. abietina*. At about the same time in Switzerland Schlaepfer-Bernhard (1969) placed *Scleroderris lagerbergii* in the genus *Ascocalyx*. Müller and Dorworth (1983), recently published on the discomycetous genera *Ascocalyx* Naumov and *Gremmeniella* Morelet. They also support the name *Ascocalyx abietina* as the correct binomial for the causal organism of Scleroderris canker. For the present, however, we will continue to use the genus name *Gremmeniella*. The nomenclature for the imperfect stage of the fungus *Brunchorstia pinea* (Karst.) v. Hohn has remained stable and is still valid.

DISTRIBUTION OF *G. ABIETINA*

At the present time *G. abietina* is found in northern Europe, North America, and Japan. Since the original report in Norway (Brunchorst 1887), the disease has been reported in all the northern European countries. The most southerly point of distribution is in central Italy. In North America, damage from Scleroderris canker first became apparent in Michigan and Wisconsin in the 1950's. The causal fungus was identified in Canada in 1962. In 1964 Ohman identified the disease in red and jack pine plantations in northern Michigan (Ohman 1966). By 1966 the fungus was widely distributed across northern Wisconsin and the Upper Peninsula of Michigan. French and Silverborg (1967) reported Scleroderris in New York. By this time the disease was well distributed across Ontario and Quebec. Scleroderris was reported in New Brunswick (Magasi 1972), in Vermont (Tatter *et al.* 1973), Alberta (Dorworth 1975), and British Columbia (Hiratsuka and Funk 1976). Up to this time reports did not differentiate between the North American and the European strain. Based on later serological typing of sample material from this area, Smerlis' (1967) report of scleroderris on black spruce (*Picea mariana* (Mill.) B.S.P.) in Quebec probably involved the European strain. The Setliff *et al.* (1975) report in New York definitely described an occurrence of the European strain. Since 1975, a major research goal has been to determine the distribution of the European strain. The reasons for this were both its more serious impact on forest stands and its more limited distribution. Following the original report in New York and the identification of a different strain of *G. abietina* as the cause of this problem, a great deal of time and effort have gone into determining the distribution of the European strain in North America (fig. 1). Since 1976, the European strain has been found in 13 counties involving roughly 23,000 hectares in New York. In Vermont, 94 plantations in 9 counties were infected. One plantation infected with the European strain was found in Coos County, New Hampshire, in 1978. All trees in this plantation were destroyed and no additional infection sites have been found in New Hampshire. In Maine the North American strain was found in Franklin County in 1978 and the European strain was found in Hancock County in

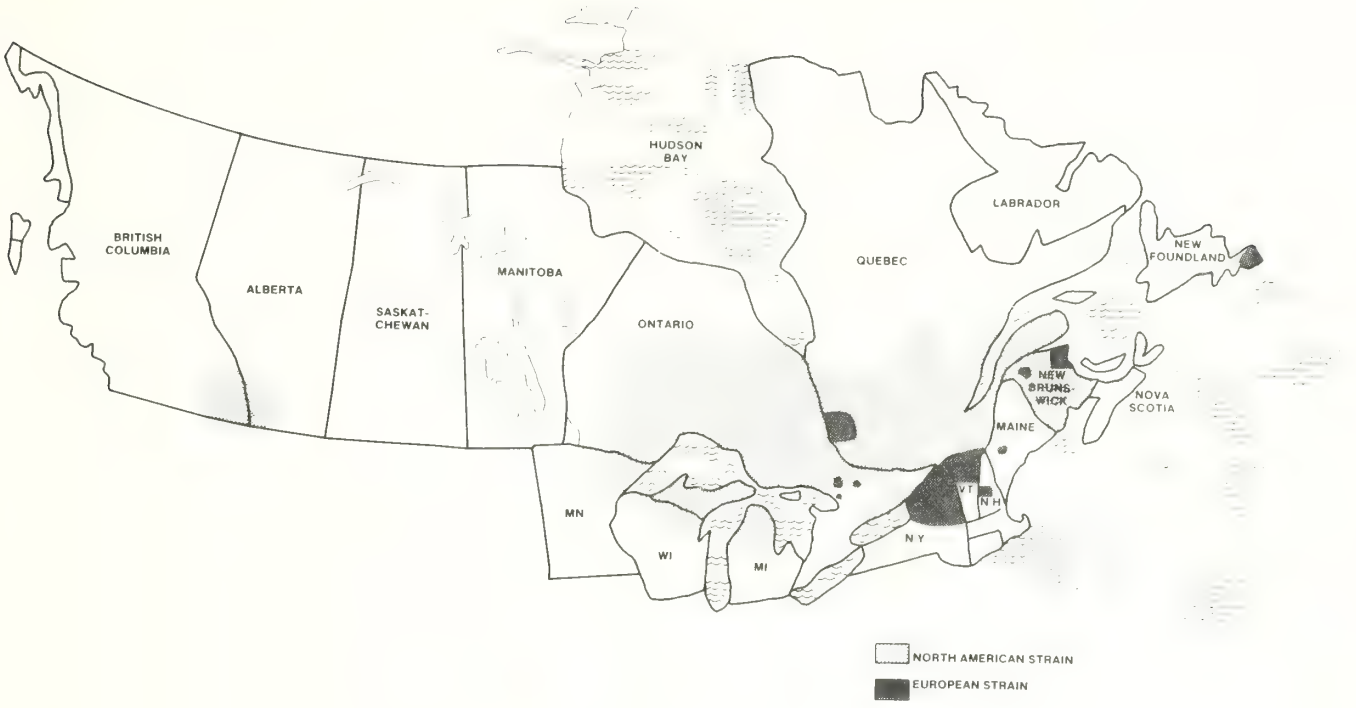

Figure 1.—Distribution of G. abietina *in North America, 1985.*

1980 and in Washington County in 1982. Infected branches were removed from the latter two plantations to prevent further disease buildup or spread. In Quebec the European strain was found in a 10-year-old red pine plantation near the New York border in 1978. This was the first positive record of the European strain in Canada. In 1979 personnel at the Laurention Forest Research Center found 19 additional plantations infected with the European strain. Infected branches were removed from these plantations, and the plantations have remained under surveillance for newly infected trees. The European strain was found in three plantations in Ontario in 1985.

Scleroderris canker is common in New Brunswick; about one-third of the jack pine plantations 4 years or older are infected (Magasi 1984). Most infections have been associated, however, with the North American strain. Isolates other than the North American strain of *G. abietina* have been identified serologically at nine locations in New Brunswick. Five samples were classified European race and four were classified as a race intermediate between the European and North American race. European race-like symptoms with large tree infection have not been observed in New Brunswick.

Scleroderris canker was present in a few plantations in Nova Scotia between 1972 and 1978. The race was never determined and this infection appears to have died out (Magasi 1984). No explanation is known for the disappearance of the disease in Nova Scotia, but some researchers have postulated that the fungus arrived on infected nursery stock but and was unable to maintain itself under Nova Scotia's climatic conditions.

The European strain of Scleroderris canker was first recorded near St. John's, Newfoundland, in 1979. In 1980 and 1981 the disease was detected at nine other nearby locations. Disease development and intensity of infection was spectacular in one plantation. Although a quarantine was established in 1980, the disease was detected outside of the quarantine area 60 km from St. John's in 1982 (Hudak and Singh 1984).

Except for the New York and Newfoundland areas, the damage in these newly discovered areas thus far is minimal. In most cases prompt detection and sanitization has prevented serious buildup. Research in New York during the last 6 years indicates that the disease requires a number of years to reach epidemic status. Except for a few areas in Newfoundland, epidemic levels are now present only in New York.

HOST RANGE

In the 1950's and 1960's, damage from Scleroderris canker in North America was found primarily in young red and jack pine plantations. Scotch pine was also attacked, but during the 1950's when the damage was occurring, few Scotch pine plantations had been established. A few eastern white pine were lightly infected in Ontario.

In inoculation tests in Wisconsin, no infection was obtained on any species of spruce or fir. These tests were all performed with the North American strain of *G. abietina*. Smerlis (1967) reported infection on white spruce (*P. glauca* (Moench) Voss) and black spruce by *G. abietina* in Quebec. This surprised investigators in the Lake States because they had been unable to infect these species. In 1978, serology tests of infected black spruce from the Quebec area where Smerlis had reported infection, revealed that these trees were infected with the European strain of *G. abietina*.

When research on the European strain was begun in New York in 1976, no information was available on the susceptibility of North American conifers to this strain. Field observations in northern New York indicated that red, jack, Scotch, and ponderosa pine were highly susceptible. Some resistance was seen in pole-size eastern white pine and white spruce showed only minor branch tip infection. Host range studies were begun in 1976 with a few species and were expanded to include most conifers native to the U.S. The objective of this study was to determine the susceptibility of North American conifers to the European strain of *G. abietina* when inoculated under field conditions.

Materials and Methods

Two sites in northern New York State were selected for the species resistance tests: the Boonville area, located 8 km NE of Boonville, New York and the Lake Clear site, located 14 km NW of Saranac Lake, New York. The European strain of *G. abietina* was present in both areas. When possible, 100 seedlings of each test species were planted in prepared transplant beds at each site. Each test plot was approximately 0.5×0.75 m. In most cases 2-0 seedlings were planted. In all tests infected red pine branches containing pycnidia of *G. abietina* were placed over the test trees in May or June to inoculate them. Infected branches were set on a vinyl-coated wire screen that was located 0.6 m above the ground. Inoculum remained over test seedlings throughout the year. Seedlings from 125 sources of 43 species were tested. Trees of most species were planted and tested in 2 successive years to determine an average infection rate at each site. One year after planting, the trees were rated for resistance on the basis of the number of infected seedlings. Fungus infection of seedlings was primarily determined by the presence of asexual fruiting bodies. If they were missing, isolations were made from necrotic tissue so we could identify the causal organism in the laboratory. Seedlings that were infected at the time of rating but later outgrew the infection were counted as infected. If the seedlings showed major differences in infection during the 2 years of testing, both infection ratings were given to show the range of infection.

Results

Infection rates differed widely for a given species between test sites and between years (tables 1 and 2). For example, in 1979 at Lake Clear only 8 percent of the Mugo pine (*P. mugo* Turra) seedlings were infected by *G. abietina*. In 1980 at the same site, however, the infection rate was 100 percent. Thus the potential for severe infection was present in 1979 but environmental conditions were not as favorable as in 1980.

G. abietina infected and produced conidia on all 16 pine species tested. Every species had more than 50 percent infection in at least one test plot. Species such as ponderosa, Monterey (*P. radiata* D. Don), red, and western white pine (*P. monticola* Dougl.) consistently had more than 90 percent seedling infection. Most of these infected seedlings died shortly after symptoms appeared. Infected Scotch and jack pine recovered somewhat although many of the recovered trees became re-infected and died during the second test year.

Within the genus *Picea*, Sitka spruce (*P. sitchensis* (Bong.) Carr.) was the most susceptible. In 1979 this species was 100 percent infected at both sites. One year later 74 percent of them died. Englemann spruce (*P. engelmannii* Parry) and Norway spruce (*P. abies* Karst.) were also severely infected in at least one test plot. The infected branch tips on seedlings of both species dropped off, however, and the trees recovered. White, red (*P. rubens*) Sarg., and black spruce showed only minor branch tip dieback; these seedlings also later recovered. Conidia of *G. abietina* were found on the dead branch tips of all three species.

Infected branch tips with conidia were found in all *Abies* species tested. Infection was light on all species except one plot of silver fir (*Abies amabilis*

Table 1.—*Susceptibility of seedlings of the genera* Pinus *and* Picea *to European strain of* G. abietina

Species	Susceptibility rating[1]
Pinus spp. (pine)	3
P. virginiana (Virginia)	3
P. echinata (shortleaf)	3
P. thunbergii (Japanese black)	3
P. taeda (loblolly)	3
P. resinosa (red)	3
P. strobus (eastern white)	2-3
P. nigra (Austrian)	3
P. mugo (Mugo)	2-3
P. monticola (western white)	3
P. ponderosa (ponderosa)	3
P. lambertiana (sugar)	3
P. contorta (lodgepole)	3
P. banksiana (jack)	2-3
P. sylvestris (Scotch)	2-3
P. rigida (pitch)	3
P. radiata (Monterey)	3
Picea spp. (spruce)	
P. sitchensis (Sitka)	3
P. engelmannii (Engelmann)	3
P. abies (Norway)	2-3
P. glauca (white)	1-2
P. mariana (black)	1
P. pungens (blue)	2-3
P. rubens (red)	1

[1]Susceptibility rating is based on the number of seedlings infected 1 year after inoculation. Seedlings that later outgrew the infection were still counted as being infected. A dual rating such as 2-3 means that the average infection was 2 for 1 year but was 3 for the other year.

0 = immune; 1 = from 1 to 9 percent of seedlings infected;
2 = from 10 to 49 percent of seedlings infected;
3 = 50 percent or more of seedlings infected.

These ratings are based on 100 tree plots at two sites. The tests were repeated a second time with different trees so the total sample size was 400 trees for each species.

Table 2.—*Susceptibility of seedlings of the genera* Abies, Thuja, Tsuga, Larix, *and* Pseudotsuga *to European strain of* G. abietina

Species	Susceptibility rating[1]
Abies spp. (fir)	
A. balsamea (balsam)	0-1
A. fraseri (Fraser)	1-2
A. grandis (grand)	1
A. magnifica (California red)	1
A. procera (noble)	1
A. concolor (white)	1-2
A. amabilis (Pacific silver)	2
Thuja spp. (cedar)	
T. plicata (western red)	0
T. occidentalis (northern white)	0
Tsuga spp. (hemlock)	
T. heterophylla (western)	1-3
T. canadensis (eastern)	3
Pseudotsuga menziesii (Douglas-fir)	1-3
Larix spp. (larch)	
L. leptolepis (Japanese)	1
L. laricina (tamarack)	1
L. occidentalis (western)	3
L. gmelini dahurica (Mongolian)	3
L. sibirica (Siberian)	3
L. eurolepis (hybrid)	3
L. sudetica (Sudeten)	3

[1]Susceptibility rating is based on the number of seedlings infected 1 year after inoculation. Seedlings that later outgrew the infection were still counted as being infected. A dual rating such as 2-3 means that the average infection was 2 for 1 year but was 3 for the other year.

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(Dougl.) Forbes) where 65 percent of the test seedlings had infected tips. One year later all fir seedlings had overgrown the infection and appeared to be healthy. Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) seedlings were moderately to heavily infected as measured by dead branch tips, but these seedlings also recovered from the infection. Both eastern hemlock (*Tsuga canadensis* (L.) Carr.) and western hemlock (*T. heterophylla* (Raf.) Sarg.) were heavily infected (90 + percent) in these tests but recovered within 1 year. Eastern hemlock seedlings growing wild near infected pines in northern New York were resistant to *G. abietina*. Northern white-cedar (*Thuja occidentalis* L.) and western red cedar (*T. plicata* D. Don) appeared to be immune to

G. abietina. Tamarack (*Larix laricina* (Du Roi) K. Koch) and Japanese larch (*L. leptolepis* (Sieb. & Zucc. Gord.)) were resistant with only a few branch tips infected. Other *Larix* species tested were susceptible.

Discussion and Conclusion

Based on the results of this work we know that the European strain of *G. abietina* is able to infect most of our North American conifers. The most serious damage will be to the hard pine species. Most of the infected hard pine seedlings eventually die. Sitka spruce also appears to be susceptible to the European strain and many of the infected spruce die. If the European strain of *G. abietina* spreads west into the natural range of Sitka spruce and ponderosa and lodgepole pine, it is possible that these three species could be severely damaged. No information is available, however, as to whether environmental conditions in the West would be favorable for infection by Scleroderris canker. Low precipitation and relative humidity could prevent epidemics from developing. Conditions necessary for Scleroderris canker infection are several days of cool, moist weather with high relative humidity when the fruiting bodies are mature (usually May to July). Whether these climatic conditions would develop often enough in the western States to support a Scleroderris canker epidemic is unknown. In the Lake States, the climatic conditions are similar to those found in the northeastern U.S. Our results indicate that the European strain will be very damaging in the Lake States, especially to red pine. No evidence of resistance was found in red pine seedlings from seed collected from 39 sources. Except for Sitka and perhaps Engelmann spruce, the *Picea* spp. appear to be resistant to *G. abietina*. Infection was light and seedlings that were infected usually recovered. Forest managers should be able to plant *Picea* spp. seedlings with little fear that Scleroderris canker will be a major problem. All the firs in this test were resistant and no problems should be experienced with this group. This is also true for Douglas-fir, eastern and western hemlock, eastern larch, northern white-cedar, and western red cedar. Although Japanese larch appears to be resistant, the European larch varieties were badly infected. Land managers should use caution with this group until more data are available.

SHORT DISTANCE SPORE DISSEMINATION

In a 2-year study of ascospore release of the North American strain of *G. abietina* in northern Michigan, ascospores were collected from April 9 to October 14 using Rotorod spore collectors.[2] The major spore release period was from May 15 to September 3 (Skilling 1969). Spore discharge and recovery were closely related to rainfall. During 1967, more than 96 percent of the spores were recovered within 24 hours after rain. No conidia of the asexual stage were collected by the Rotorod spore traps during the experiment. Conidia were collected, however, from May 17 to September 14 on vaseline slides placed 5 mm from infected branches. Therefore, the conidia were rain splashed from the pycnidia onto the slides but were probably not wind disseminated to the more distant Rotorod traps. Pycnidia collected at several areas in Michigan and Wisconsin during a 3-year period had viable conidia present from late April to mid-October with the maximum number present during early June.

No spore release information was available for conidia of the European strain. To determine at what time and in what numbers the conidia were present in infected plantations, we monitored spore release in two areas of New York during 1977 and 1978. These two areas were the Boonville and Lake Clear sites previously described for the host range studies. Ascospores of the perfect state of the European strain of *G. abietina* are rare in New York State, but they have been found in a few plantations. Apparently, conidia are primarily important in the spread of the fungus. Thus, the emphasis of our study was placed on characterizing conidial dispersal.

Materials and Methods

Precipitation was recorded weekly at both areas using standard U.S. Weather Bureau rain gauges. To trap *G. abietina* conidia, two vaseline-coated microscope slides were exposed at each site. A dead red pine branch with mature pycnidia of *G. abietina* was mounted on the trap approximately 5 mm from each slide. The slides were changed at weekly intervals and the number of conidia was determined by making three passes across each slide at 400X magnification. (This procedure has been described by Ostry

[2]*Mention of trade names does not imply endorsement by the USDA Forest Service.*

and Nicholls 1982.) In 1977 the spore traps were operated from March 28 to November 21. Because spores were trapped during the first week of the study in 1977, spore dispersal could have commenced prior to the beginning of the study. As a result, the trapping period was expanded in 1978 to cover the entire year. Spore counts from the two areas were combined to give an average dispersal count for the northern New York region.

Results and Discussion

In 1977 and 1978 the major spore release was during May, June, and July. Peak release was in June in both years (fig. 2). Conidia were trapped in every month during 1978. The number of conidia released was not related to total weekly rainfall, but no conidia were collected during any week without rain (table 3). Spores were only released during the winter months when precipitation was as rain; no spores were released during snowfall. Apparently, condidia dispersal with the European strain is possible anytime free moisture is present and the temperature is above freezing.

In a separate study in New York, Luley and Manion (1984) used both petroleum-coated slides and monofilament spore traps to study spore dispersal. No ascospores were collected during the 17-week sampling period on either type of trap. The maximum number of conidia were collected from early May through early June, which coincides with the period of elongation and development of red pine shoots. Conidia were trapped from ground level to 12 m above the ground with no significant difference in spore density at the different elevations. Red pine seedlings exposed to infection at the various heights were infected from the groundline to 12 m.

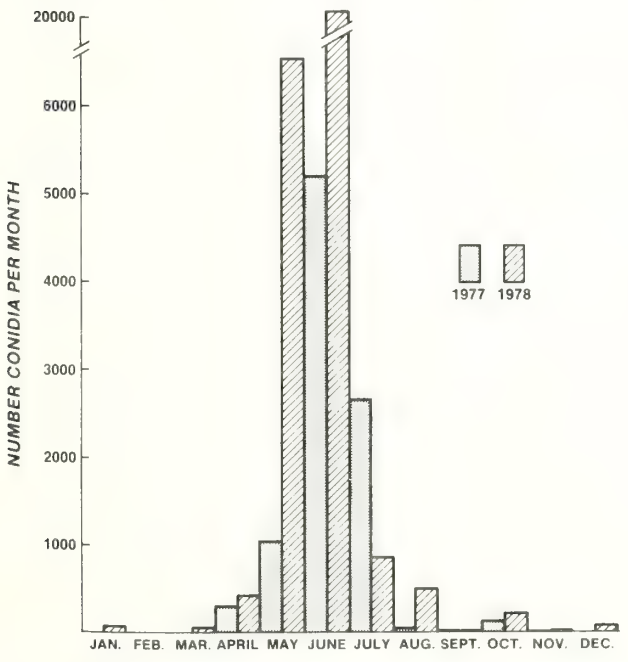

Figure 2.—Total conidia dispersal of G. abietina *at Lake Clear and Boonville, New York, 1977-1978.*

Table 3.—*Combined conidia dispersal of* G. abietina *at Lake Clear and Boonville, New York*

Month	1977		1978	
	Conida	Rainfall	Conida	Rainfall
	Ave. no.	*Ave. cm*	*Ave. no.*	*Ave. cm*
January	-	-	74	16.2
February	-	-	1	4.3
March	-	-	28	5.1
April	295	9.4	424	9.3
May	1,052	3.0	6,542	4.3
June	5,200	9.2	20,140	11.0
July	2,642	12.5	863	5.5
August	56	16.2	503	8.7
September	32	22.7	26	12.0
October	133	10.1	212	8.8
November	12	5.2	26	3.8
December	-	-	76	13.2

LONG DISTANCE SPORE DISSEMINATION

Conidia studies of the North American strain in Michigan indicated that conidia were only disseminated over short distances, such as within an individual tree, while ascospores were responsible for long distance fungus spread (Skilling 1969). Spore dispersal studies of the European strain in New York in 1977 and 1978 showed that conidia were rain-splash disseminated for short distances throughout the year. No information was available on long-distance movement of conidia in New York. Because the wind-blown ascospore stage of the European strain of *G. abietina* is rare in New York, the question of how the causal fungus moved so rapidly through New York plantations remains to be answered.

Materials and Methods

To determine the importance of the long distance movement of conidia of the European strain, a new spore-trapping procedure was used in 1979. Two areas were selected for this study. One was located on the Tug Hill plateau near Lowville, New York,

and the second area was located near Saranac Lake, New York. These two sites each had a small infection area next to an open field with no other inoculum present. Vaseline-coated spore traps were placed from 0 to 610 m from the inoculum source.

Results and Discussion

The number of conidia collected at the spore trap sites dropped rapidly as distance from the inoculum source increased (table 4). Small numbers of conidia, however, were trapped at the 610 m trap indicating that at least some wind transport of conidia was possible.

The conidia of *G. abietina* are approximately the same size as the ascospores. If they become airborne, they should be able to move by air currents with about the same efficiency. The major difference between the two spore stages with respect to dispersal is that conidia are produced in spore tendrils that ooze out of the pycnidia during moist weather. These spore tentrils are probably diluted by rain, but the spores rely on wind or some other agent to propel them into air currents where they can be carried away. The ascospores, however, are forcefully expelled from the apothecium for a distance of up to 25 mm in calm air (Skilling 1968). This distance is sufficient for the spores to reach passing wind currents around the apothecium in the first step toward long-distance spread. This system explains why many more ascospores than conidia are collected in long-distance spore dissemination studies of the North American strain. In New York, however, even though the ascospores are not present in large numbers, enough conidia become airborne to spread the fungus from one plantation to another. Once airborne, these hyaline, 4-celled spores are durable. Zajechowski and Bergdahl (1983), sprayed conidia on living red pine foliage in the greenhouse and in the field. After 20 days spore viability was 27 percent on greenhouse seedlings while that of spores in the field was 49 percent on seedlings protected from rain but only 2 percent on unprotected seedlings. It appears that airborne conidia can spread the fungus to new areas if they land on a suitable target needle. The 30 to 60 km distances between certain old and new infection sites in New York and Quebec are probably the result of airborne conidial.

Table 4.—*Long-distance transport of* G. abietina *conidia in New York during 1979*

Area	Distance from inoculum source						Total conidia[2]
	0	61	122	305[1]	305	610	
	---------- *M* ----------						*Number*
Saranac lake	1,723	54	13	3	17	11	1,821
Tug	49	39	25	10	9	18	150

[1]Rotorod collection point.

[2]All conidia were collected on vaseline slides except for one rotorod collection point at 305 m.

Insects have also been considered as vectors of *G. abietina*. Frederick *et al*. (1976), were able to infect jack pine by placing conidia-bearing beetles on wounded seedlings. A study by Lanier *et al*. (1984), examined the role of the twig-infesting scolytid beetles *Pityophthorous pulicarius* and *P. puberulus* in infecting trees with Scleroderris canker. These beetles were often found breeding in twigs killed by *G. abietina*. Although these insects were exonerated from the role of suspected vectors of Scleroderris canker, a significantly reduced infection rate in red pines treated with the systemic insecticide carbofuran indicated that insects may nonetheless exacerbate the disease outbreak by providing infection courts for conidia.

INFECTION BIOLOGY

Primary infection for the North American strain is by windblown ascospores. These are formed in fruit bodies on dead infected branches. The spores are disseminated during moist weather from April to October although major infection is in June and July. Although most spores are disseminated only a few meters from the infected branch, many times new infections have appeared several kilometers from any existing infections. The ascospores infect through buds or at the bases of needles in early summer, and infected branch tips are usually dead the following summer. According to Patton *et al*. (1984), the spore germ tube infects shoots through stomata on the abaxial surface of bracts that subtend short shoots. The germ tube penetrates between guard cells, sparsely colonizes branch tissue, and reaches the periderm that separates branch from stem tissue by late summer or fall. The fungus crosses this periderm in early February when the host plant is dormant. It then rapidly colonizes the short shoot and surrounding cortical tissue. This invasion produces a resinous brown necrotic area of cortical parenchyma and phloem beneath the branch as the first visible symptom of infection. Sletten (1971), working in Norway with *P. sylvestris*, found that trees inoculated with *G. abietina* during winter dormancy showed symptoms the following spring and summer. However, trees inoculated in the growing season of

1 year showed no symptoms until the growing season of the next year. Sletten's work agrees with studies at the North Central Forest Experiment Station in that most damage to the host plant by Scleroderris occurs while the host is dormant. Lang and Schütt (1974), in Germany also found that the mycelium remained under and between the leaf scales during the growing season, invading them in the autumn by penetrating the outer wall of the epidermis directly and growing through the periderm into the inner tissues of the shoots. Siepmann (1976) found that after inoculation with conidia in July 1974, hyphae were found in the epidermis and hypodermis of long shoots by the end of August and in the cortical parenchyma of the needle base by January 1975. Invasion of the bud scales of short shoot buds was observed in early December 1974, beginning in the dead cells of the blade margin and extending into the green tissue of the scales.

The long period of time between spore infection and the first visible symptoms frequently leads to the shipment of infected nursery stock. This is especially true with fall shipments because no visable symptoms are present in the fall.

Dorworth (1979), studied the effect of inoculum concentration on infection of red pine by the North American strain of *G. abietina*. Conidial suspensions were sprayed on red pine seedlings during June. A concentration of 2.5×10^8 conidia per square meter of seedbed was required to kill 50 percent of the seedlings.

The first symptom of infection by *G. abietina* is usually the dieback of buds and the discoloration at the base of needles on the previous season's growth (Inset front cover). Beginning at their base, infected needles turn orange during early May approximately 9 months after infection. By midsummer the needles are brown. These needles are loose and usually drop off leaving a bare branch tip. A few months after an infected branch dies, pycnidia appear near the base of dead needle fasicles. Asexual spores (conidia) ooze out of these pycnida during wet weather from April to October (fig. 3). As mentioned earlier, these spores are primarily transported by rain splash to nearby branches, but recent studies have shown that these conidia can also be transmitted long distances by the wind. The apothecial fruiting bodies of the North American strain appear in early summer on branches that have been dead for 1 or 2 years (fig. 4). The apothecia are also commonly found at the base of dead needle fasicles and are often found in association with the pycnidial stage (fig. 5).

Figure 3.—Conidia of G. abietina.

After infection, the fungus may grow down the branch for a short distance until it reaches the main stem of the tree; young trees are girdled quickly and die within a few months. In many cases, however, the fungus only grows outward for 3 to 4 cm from the infection spot. At this point the fungus is unable to survive competition from saprophytic fungi. By this time, however, it has girdled the branch and the branch dies from the infection point to the tip. It is this dieback of branch tips that is most characteristic of Scleroderris canker and when multiple branches are killed, is the primary cause of tree death. Stem infections frequently form a canker, and it is this canker that gives the disease its name (fig. 6). This canker may eventually be overgrown but will usually deform the stem. Small cankers are common on branches infected with the European strain but are rarely found on branches infected with the North American strain. A characteristic yellow-green stain is commonly observed in the cambial zone of recently killed tissue.

The infection biology of the European strain is similar to the North American strain but with the following exceptions. The apothecia that produce windblown ascospores are rare, at least in New York

Figure 4.—Apothecia of G. abietina.

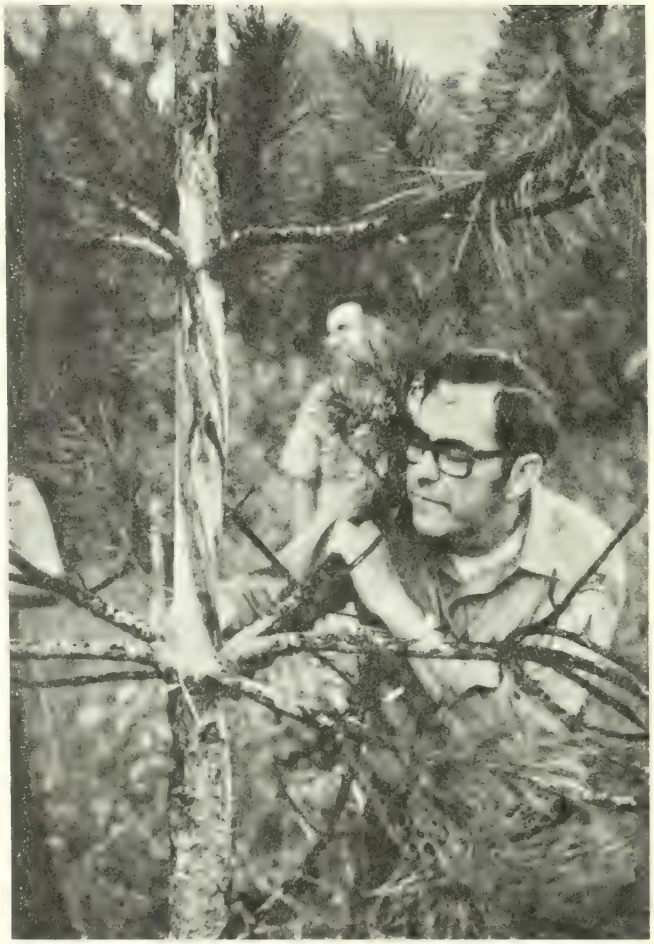

Figure 6.—Canker on red pine caused by G. abietina.

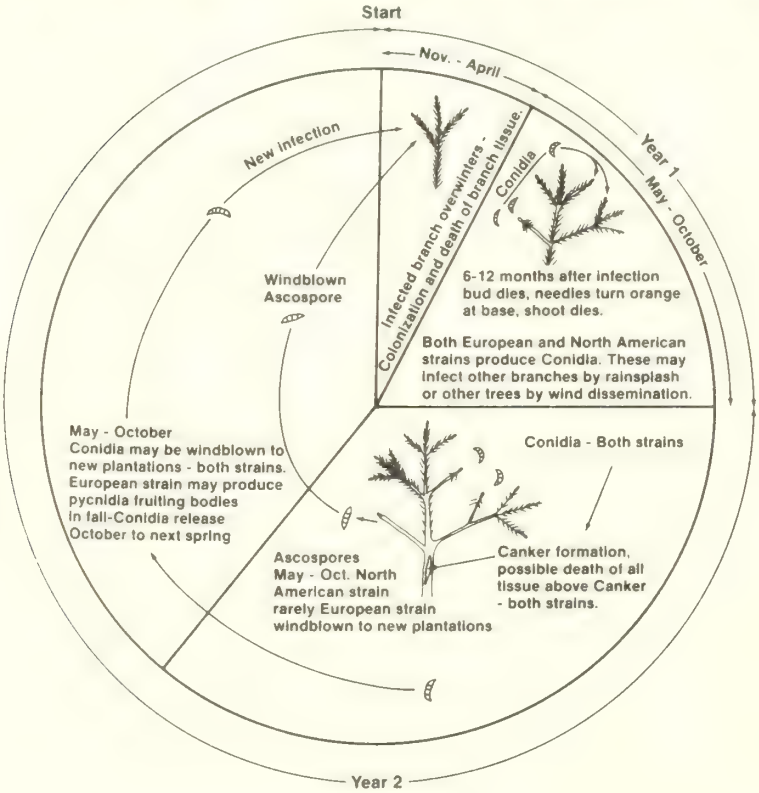
Start
Nov. - April
Year 1
May - October
Year 2
New infection
Windblown Ascospore
Infected branch overwinters - Colonization and death of branch tissue.
Conidia
6-12 months after infection bud dies, needles turn orange at base, shoot dies.
Both European and North American strains produce Conidia. These may infect other branches by rainsplash or other trees by wind dissemination.
May - October
Conidia may be windblown to new plantations - both strains. European strain may produce pycnidia fruiting bodies in fall-Conidia release October to next spring
Conidia - Both strains
Canker formation, possible death of all tissue above Canker - both strains.
Ascospores May - Oct. North American strain rarely European strain windblown to new plantations

Figure 5.—Disease cycle of G. abietina.

State and in some areas in Europe. Most spread appears to be the result of wind and rainsplash movement of conidial. The European strain produces a second crop of pycnidia during the late fall in New York. Conidia from these fruiting bodies are sometimes released during wet winter periods when the temperature is above freezing.

During the winter of 1980-1981, potted red pine seedlings were exposed at Lake Clear, New York, to determine if infection could occur during the winter months from these conidia. During February 1981 the weather was unusually warm for several days. The mature pycnidia present released conidia during this period and exposed seedlings were infected (table 5).

The European strain, therefore, can release conidia during the winter months and these conidia are able to infect conifer seedlings if the weather is suitable. Temperature must be above freezing and sufficient rain must fall to liberate spores, but the needed duration of these conditions is not known.

SPREAD WITHIN STANDS

Since Scleroderris canker first appeared in North America, investigators have been trying to determine why epidemics develop within certain plantations. Early work by Skilling and Cordell (1966) showed that the highest infection rates were in plantations less than 5 years of age. Plantations more than 15 years old were lightly infected. Furthur examination revealed that infected nursery stock was being shipped to new plantations. Damage from Scleroderris canker was related to the amount of new infection that became established during the early life of the plantation. If a high percent of seedlings became infected during the first 3 or 4 years after planting, most of the seedlings died. If the trees became infected at a later period, the trees were too tall to be killed by the time the infection was distributed throughout the stand. The lower branches (up to 2 m above ground) would die but the rest of the tree would remain alive and few trees would be killed.

Table 5.—*Red pine seedling exposed to pycnidia of* G. abietina *at Lake Clear, New York*[1]

Period exposed to infection	Seedlings exposed	Seedlings infected	Seedlings infected
	------ *Number* ------		*Percent*
12/28/80 to 1/12/81	10	0	0
1/12/81 to 1/26/81	10	0	0
1/26/81 to 2/9/81	10	8	80
2/9/81 to 2/23/81	10	9	90
2/23/81 to 3/9/81	10	1	10
3/9/81 to 3/23/81	10	0	0

[1]Seedlings were only exposed to the inoculum for the test period shown. At the end of each exposure period the seedlings were removed to an area with no inoculum and observed in May 1981 for symptom development.

The situation with the European strain is different because the fungus has the ability to attack trees of all sizes. When the initial epidemic of Scleroderris canker was observed in New York State, disease incidence was so high that it appeared that most of the red pine stands would soon be killed. Many of these stands had a large amount of highly susceptible live lower branches available for rapid buildup of the pathogen. Within 2 years the branches on the lower 5 m of most red pine stands were killed by the fungus. Then, either because of less favorable climate for infection or because the upper branches were less susceptible, the upper crown infection advanced at a slower rate. Although thousands of trees were killed during the first infection wave (Front cover), surviving trees continued to grow even though their lower branches died. At this point information was needed to determine what the future disease impact would be on these remaining stands. It was important to know when stands would reach the critical stage where severe upper crown infection would kill the trees.

Materials and Methods

In 1976 the New York Department of Environmental Conservation established eight 20- by 30-m permanent study plots in Lewis County, New York. The purpose of these plots was to monitor the rate of upward spread of Scleroderris canker in older stands. All plots were located in 45-year-old stands—two plots were in Scotch pine and six plots were in red pine stands. At the time the plots were established, from 90 to 100 percent of trees in the stands were infected with Scleroderris canker. Each plot was measured annually. The height of each tree and the height of the highest infected branch in each tree were recorded.

Results and Discussion

We observed large differences in the amount of healthy crown from year to year in each of the eight

Table 6.—*The rate of vertical spread of Scleroderris canker in 45-year-old red and Scotch pine stands in Lewis Co., New York*[1]

(In meters)

	Year	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6[2]	Plot 7	Plot 8
Average tree height	1976	16.7	14.9	16.7	14.7	15.2	11.2	14.9	14.8
	1980	18.2	16.4	18.4	16.2	16.4	13.2	16.6	16.6
	1983	19.3	17.4	19.2	17.3	17.6	14.4	17.8	17.5
Average infection height	1976	10.6	9.8	11.9	9.3	9.3	5.8	10.1	10.8
	1980	13.9	11.6	15.4	11.8	11.7	7.8	11.8	12.0
	1983	14.5	12.2	16.1	12.6	14.0	9.8	12.6	12.7
Healthy crown	1976	6.1	5.1	4.8	5.4	5.9	5.4	4.8	4.0
	1980	4.3	4.8	3.0	4.4	4.7	5.4	4.8	4.6
	1983	4.8	5.2	3.1	4.7	3.6	4.6	5.2	5.1

[1]Plots 3 and 5 are located in Scotch pine stands. All remaining plots are in red pine.
[2]Plot 6 was not measured in 1981.

sample plots as well as between plots (table 6). In 1980 moderate Scleroderris canker infection occurred throughout Lewis County. During this period the length of healthy crown was reduced in six of the eight sampled stands. An average of only 3 m of healthy crown was present on the trees in one of the Scotch pine plots in 1980. This is a small crown for trees averaging 18.4 m in height. In contrast, the years from 1980 to 1983 were light infection years for *G. abietina*. As a result the length of healthy crown on these same trees actually increased. Looking at the extent of disease development in the eight stands for the 7-year period we observed that total healthy crown length decreased in five stands and increased slightly in three stands. The decrease in healthy crown appears important in one of the Scotch pine plots (plot 5) but so far has had no measurable effect on tree height growth. No heavy infection years have been recorded since the plots were established, so we still do not know the final disease impact on these eight stands. The tree crowns appear to be getting smaller in general but we have observed no growth reduction or dead trees. If weather conditions are conducive to heavy infection for 2 or 3 successive years, we believe that many of the trees will die. Up to this time, however, the plot data do not support this conclusion and a final analysis must depend on additional data.

Carvin and Manion (1984) followed the development of Scleroderris canker on 13 plots located in 8 red pine stands in northern New York from 1978 to 1982. The trees in these stands were from 15 to 20 years old and from 3.7 to 5.9 m tall. During the first 2 years of this survey, disease incidence increased as reflected by the positive disease rates. However, the disease slowed dramatically during the 1979 to 1980 period. They concluded that intensification of Scleroderris canker in young red pine plantations in New York appeared to be progressively slowing down. They also found some plantations that showed signs of recovery. Their data suggest that environmental factors may have a significant affect on the rate of disease incidence both on a local and a regional basis. They caution that, "although the disease seems to be moving at a slow rate currently, there is always the potential for a return to the serious and rapid intensification of the mid-1970's".

Carvin and Manion's results in young stands are similar to our results from the spread studies in 45-year-old red and Scotch pine stands. The New York Scleroderris epidemic apparently developed as the result of favorable infection conditions for several consecutive years along with the availability of a large volume of lower crown pine foliage. This combination resulted in the rapid development of an extremely serious epidemic. With less favorable infection conditions and the loss of the susceptible lower foliage, the infection is now progressing at a much slower rate. Individual stands are still showing serious infection conditions, but the Statewide epidemic that developed in the mid-1970's has not reappeared.

Kurkela (1984) reported on the spread of *G. abietina* within stands in Finland. He stated that epidemics can develop only when a large amount of host stands are potentially susceptible. This agrees closely with the situation that developed in northern New York in the mid-1970's. Kurkela also states that during the winter resistance may be broken or fail to develop. Pines introduced from different climatic conditions or planted on unfavorable sites are most likely to become susceptible. In that sense a

Gremmeniella epidemic in pine stands can be a man-made problem. Kurkela also feels that with increased inoculum potential the pathogen is also able to attack more resistant local pines. This situation also developed in New York during the 1970's epidemic. Strip plantings of red pine became severely infected by *G. abietina*. At the same time the fungus infected adjacent strip plantings of resistant white spruce resulting in branch dieback. Following the death of the red pine and subsequent reduction in inoculum, the white spruce infection declined to undetectable levels. Thus, the white spruce became infected under heavy inoculum loads but when these were removed, the causal fungus was not able to continue on white spruce alone. Hudler *et al.* (1983) have also shown that species differ in susceptibility based on inoculum dose.

VARIATION OF FUNGUS ISOLATES

In the introduction, we referred to the North American and European strains of *G. abietina*. These two strains have been separated on the basis of their ability to infect the upper crown of large trees and on their immunogenic reaction to European isolates of *G. abietina*. Dorworth and Krywienczyk (1975) proposed three races.[3] The North American race was based on a group of serologically similar isolates from Canada and the United States that differed predictably in serologic reaction from a group of isolates from Europe, termed thereafter the European race. They also established an "Asian race" based on a different serologic reaction shown by five isolates from Hokkaido, Japan. This grouping of three races has proved useful thus far. However, as more isolates have been serologically tested in eastern North America, additional differences in serological reaction have appeared. Both Skilling (1981) and Wendler *et al.* (1980) have characterized an "intermediate race" that responds both to European and North American antisera when subjected to serologic examination. For practical regulatory purposes, the intermediate race or strain has been grouped with the European strain isolates because these isolates have shown field pathogenicity reactions that were identical to the European isolates (they were able to infect trees of all sizes). As the serological techniques are increasingly refined, more physiological strains probably will be defined. It is not clear whether these physiological strains will also differ in pathogenicity. The intermediate physiological strain as characterized by serology appears pathogenically similar to the European strain. Thus all pathogenic strains are physiologic strains but the converse may not be true (Dorworth 1981). At this time no pathogenic studies have been conducted using the Asian strain under North American conditions so we cannot comment on its pathogenic relation to the European and North American strains. Yokota (1975) describes the Asian strain as a top invader of pole-sized *Abies sachelinenis* Mast. weighted to or near the ground during winter by snow at higher altitudes in Hokkaido, Japan. The most pronounced symptom, upper crown dieback, appeared after the trees resumed an erect position in the spring. It is unknown how the Asian strain would react to North American species under North American climatic conditions.

Two confusing situations with fungus variation were reported by Skilling (1984a). These should be mentioned to avoid the impression that strain identification is completely understood. In the first case an isolate obtained from black spruce in Laurentide Park in Quebec, Canada, tested as European strain. However, this isolate only infected the lower branches of black spruce trees and produced abundant apothecia of *G. abietina*. Both characteristics are normally found only on trees infected with the North American strain. In the second case an unusual isolate was identified in northern New York on red and jack pine trees. This isolate was found in the upper crowns of large trees, which is characteristic of the European strain. It also produced large quantities of ascospores under field conditions. Single ascospore cultures derived from one apothecium produced mycelial cultures that gave either North American or European immunogenic reactions depending on which single-spore culture was used. This suggests the possibility of hybridization between European and North American strains (Furnier *et al.* 1984). Conidia produced from mycelium of these two strains were used to inoculate seedlings of white spruce, and jack, Scotch, lodgepole, red, and white pine. Both types of conidia were able to infect all species inoculated, but the conidia produced from the North American mycelium killed many more seedlings of every tree species inoculated. This was the reverse of what would be expected and emphasizes that much more information is still needed on the relation between physiological and pathological strains.

At the present time the North American strain has been identified in Michigan, Wisconsin, Minnesota, New York, Vermont, Maine, Quebec, Ontario, New Brunswick, Alberta, British Columbia, and probably Nova Scotia. The European strain has been found in New York, Vermont, New Hampshire, Maine, Newfoundland, Quebec, Ontario, and New Brunswick (Skilling 1984a) (fig. 1).

[3]*The words race and strain are used interchangeably in this paper.*

CONTROL

Silvicutural

Because of the damage caused by *G. abietina* in pine stands, a number of studies have been established to develop control systems. Studies by Skilling (1968) showed that much of the damage and spread of this fungus in the Lake States was caused by planting infected nursery stock. Two recommendations were made to reduce these losses. The first was to avoid fall planting of nursery stock because it is impossible to identify latent infections during this period. The other recommendation was to prevent nursery stock infection by implementing a fungicide spray program, which will be discussed later. Skilling also determined that young seedlings planted within 700 m of plantations infected with the North American strain would become infected at an early age and some seedlings would die. He also determined that Scleroderris canker is most serious in forest areas above latitude 45° north or at high elevations where summers are cool and the frost-free period is less than 90 days. No relation was found between site quality and disease severity (Skilling 1984b).

Pruning lower branches of infected and healthy trees has delayed disease buildup in test plots in Vermont (Bergdahl and Ward 1981). A 12-year-old red pine plantation with 44 percent of the trees infected was pruned to a height of 1.5 to 2.0 m to remove branches infected with the European strain of *G. abietina*. Two years after pruning less than 1 percent of the pruned trees were infected while 54 percent of the trees in the untreated plantation were infected. A similar study by Bergdahl in an 18-year-old red pine stand with 59 to 100 percent of the trees infected was less effective. In this stand 22 percent of the trees in the pruned area were infected 2 years later. Most of the infection in the pruned area appeared to be latent infection missed during initial pruning.

If sites in high Scleroderris hazard zones are suitable for growth of resistant or immune species, forest managers would be wise to grow these to reduce the impact of this disease.

As the European strain moves into new geographic areas, sanitation may be one of the most effective controls. This procedure has been used successfully in New Hampshire, Maine, and Quebec. Although it will not prevent reinfection, it may prevent establishment of the disease for many years. If only a few trees are infected, pruning of infected branches may be adequate. If infection is widespread, removing the entire plantation may be necessary. Harvesting merchantable material plus chipping needle-bearing slash will greatly reduce the disease hazard although the fungus can survive on infected pruned branches for 10 months after the branches are removed (Dorworth 1972). Placing the infected branches in plastic bags has been suggested as an alternative to removing them from the plantation but a recent study showed that *G. abietina* could survive for up to 14 days in green plastic bags exposed to the sun (Davis and Dorworth 1984). The fungus was isolated from 33 to 70 percent of all branches checked. Davis and Dorworth recommended that the infected material be removed from the plantation and destroyed.

Silvicultural control in most cases is less effective with the European strain because plantation trees are susceptible throughout the entire rotation. With the North American strain, little damage will result from later fungus infections if infection can be kept at low levels until the trees are about 2 m tall.

Legal

Quarantines have been used effectively in New York, Vermont, and eastern Canada to prevent movement of plant material infected by the European strain of *G. abietina* (Barrett 1984, Laidlaw 1984). Quarantines reduce the danger of long-distance spread and appear to have prevented the movement of the European strain on cut Christmas trees and nursery stock. Because most quarantines have been specific for the European strain, the strain involved must be determined by serological procedures prior to regulatory action. The techniques have been published in manual form (Skilling and Kienzler 1983) and they are expensive and time-consuming.

Genetic

The long-term control of the European strain of *G. abietina* will require finding native and exotic trees that are resistant to this fungus. Martinsson (1984) tested seedlings from 11 lodgepole pine progenies from western Canada at 2 sites in Sweden. Field resistance seemed to only slightly depend on genetic origin of seed. Disease incidence differed greatly at the two sites and no single seed source was clearly resistant.

In northern New York Skilling and Riemenschneider (1984) tested 15 full-sib families of Scotch

pine from Sweden as well as seed from seven northern European and Asian sources. None of the seed sources showed much resistance under the high inoculum levels present at the test sites. Skilling also tested 39 seed sources of red pine for resistance to both the European and North American strains of *G. abietina*. None of these seed sources was resistant to either strain. Some preliminary evidence of resistance to *G. abietina* has been found in jack pine. In 1982, 60 families of jack pine from the Lake States were screened against both strains. These seedlings were outplanted in New York and Wisconsin. The Wisconsin test showed severe infection on all families tested. However, in the New York test, 7 seed sources from southern Wisconsin and southern Minnesota had 42 percent infection while 17 seed sources from the northern Lower Peninsula of Michigan had only 7 percent infection. Although these data are preliminary, they show evidence of some resistance in jack pine (Skilling 1984c).

Yeatman (1984) has also reported resistance of jack pine to the North American strain of *G. abietina*. In a series of range-wide jack pine provenance tests in boreal and eastern Canada, resistance to the North American strain was found among seed from western, northern, and eastern Quebec. Low infection levels were also evident in particular provenances from New Hampshire, New Brunswick, and Cape Breton. Generally, provenances from the milder, southern limits of the jack pine range were highly susceptible to the disease. They were also subject to winter desiccation when planted in severe boreal or high altitude environments.

Significant clonal differences in susceptibility to *G. abietina* were observed in 14 clones of Austrian pine (*Pinus nigra* ssp. *nigra*) (Stephan *et al*. 1984). Clones with higher resistance possessed a higher buffering capacity of pH in homogenized bark tissue of 1-year-old shoots. The monoterpenes of the bark tissue of 1-year shoots were also related to disease resistance. Myrcene and limonene content showed significant negative correlations with the attack by *G. abietina*.

Stephan (1977) also has tested four provenances of ponderosa pine in northwest Germany. After 19 years in the field the provenances from British Columbia, Washington, and Oregon grew best. The Utah provenance was slow growing and almost 100 percent were killed by *G. abietina*. In 1983, the North Central Forest Experiment Station tested 47 seed lots of ponderosa pine and 26 seed lots of lodgepole pine from 5 western regions of the United States for resistance to *G. abietina*. Duplicate plots were established at two locations in New York and one location in Wisconsin. Trees at the New York locations were exposed to the European strain *G. abietina*, while trees in the Wisconsin plot were exposed to the North American strain. The results with ponderosa pine agree with tests conducted by Stephan that show extensive mortality with this species. After 1 year of exposure to high inoculum levels, seedling mortality ranged from 87 to 100 percent for those trees exposed to the European strain and 78 to 100 percent mortality for trees exposed to the North American strain. Although lodgepole pine had lower mortality rates due to shoot sprouts developing below the infection site, the infection levels were 87 to 100 percent for the European strain and 91 to 100 percent for the North American strain. Although these data are preliminary, both species appear to be highly susceptible. Jack pine is the only pine species that has shown any major variation in resistance to *G. abietina*.

CHEMICAL

In 1959 Elmar Kohh established fungicide tests in northern Sweden at the Lovkulla Nursery to protect Scotch pine from infection by *G. abietina* (Kohh 1964). Of five fungicides tested, maneb proved to be the most effective. Kohh recommended a concentration from 0.7 to 1.0 percent active ingredients plus a wetting agent. Spray applications began when the current year's needles were 0.5 cm in length and were repeated at 2-week intervals. He recommended five to six sprays during the summer. Kohh's paper was published at an opportune time for pathologists in North America because this was the time of the first identified losses from Scleroderris canker in North American nurseries. Kohh's nursery control recommendations were used as a starting point until better fungicide controls could be developed.

New control recommendations were released for the Lake States region in 1970. They advise the use of maneb at 3 percent active ingredient using 12 applications from May 21 to October 30 (Skilling and Waddell 1970). In 1974 these recommendations were updated based on tests with additional fungicides (Skilling and Waddell 1974). They recommended chlorothalonil or chlorothalonil and cycloheximide at 0.3 percent concentration of active ingredients. The number of sprays was reduced to seven and the application period was from late May to mid-August. All of Skilling's fungicide tests were against the North American strain. The fungicide mixture chlorothalonil and cycloheximide was originally tested by Klingstrom in Sweden. He found that the addition of 1 part of cycloheximide to 1,000 parts of chlorothalonil resulted in better disease control of *Lophodermium, Phacidium*, and *Scleroderris*

(Klingstrom 1974). He felt that the cycloheximide had a systemic action that made the process less dependent on weather conditions at the time of spraying. This fungicide mixture has never been commercially available in North America and at present chlorothalonil is the only fungicide registered for control of *G. abietina* in the United States.

In Quebec, Smerlis (1980) has also tested fungicides for control of *G. abietina*. He tested 17 fungicides against the North American strain and the strain found on black spruce, which he called the Quebec strain. He was able to control the North American strain on jack and red pine seedlings with two applications at 2-week intervals using a 2 percent water suspension of chlorothalonil or anilazine. He recommended spraying when the current-year leaders were from 5- to 10-cm long. He was able to control the disease on black spruce with only one spray application of chlorothalonil in mid-July. Skilling *et al*. (1984) were not able to control the European strain with the limited spray schedule reported by Smerlis. Although they applied chlorothalonil and chlorothalonil plus cycloheximide up to 12 times during the growing season, they were not able to achieve the 100-percent control they felt was necessary for nursery stock. They achieved the same degree of control with 4 sprays of chlorothalonil at 1 percent active ingredients as with 12 sprays at 0.3 percent active ingredients. The longer period of spore dissemination by the European strain makes fungicide control in nurseries more difficult. In a fungicide test in New York during 1980-1981, test seedlings were infected during an unusually warm, wet period in February. These seedlings had not been treated with fungicides since the previous fall. The results of this study indicate that because of the long infection period for the European strain, it will be difficult for nursery managers to protect seedlings throughout the entire year. To produce disease-free stock it will be necessary to keep a protective fungicide on seedlings from early spring until the seedlings are covered by snow in late fall. This is the only way to fully protect seedlings and prevent the spread of this fungus from nurseries into plantations. At this time no pesticide treatment can be recommended for infected plantations because of the excessive cost of the large number of fungicide applications necessary. It is important to keep susceptible plantations free of this disease wherever possible.

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PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Skilling, Darroll D.; Schneider, Bruce; Fasking, Donald.
Biology and control of Scleroderris canker in North America. Res. Pap. NC-275. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 19 p.

Describes the taxonomy, distribution biology, and control of the European and North American strains of Scleroderris canker as it applies to North America.

KEY WORDS: Scleroderris canker, tree diseases, forest management, fungus variation, disease control.

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